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Assessing the Impacts of Electric Vehicle Recharging Infrastructure Deployment Efforts in the European Union

Christian Thiel *, Andreea Julea, Beatriz Acosta Iborra, Nerea De Miguel Echevarria, Emanuela Peduzzi, Enrico Pisoni, Jonatan J. Gómez Vilchez and Jette Krause

European Commission, Joint Research Centre (JRC), 21027 Ispra, Italy; Andreea.JULEA@ec.europa.eu (A.J.); Beatriz.ACOSTA-IBORRA@ec.europa.eu (B.A.I.); nereademiguel@yahoo.es (N.D.M.E.); Emanuela.PEDUZZI@ec.europa.eu (E.P.); Enrico.PISONI@ec.europa.eu (E.P.); Jonatan.GOMEZ-VILCHEZ@ec.europa.eu (J.J.G.V.); Jette.KRAUSE@ec.europa.eu (J.K.)

* Correspondence: Christian.THIEL@ec.europa.eu; Tel.: +39-033278-9207

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Abstract: Electric vehicles (EVs) can play an important role in improving the European Union's (EU)'s energy supply security, reducing the environmental impact of transport, and increasing EU competitiveness. The EU aims at fostering the synchronised deployment of EVs and necessary recharging infrastructure. There is currently a lack of studies in the literature for analysing the societal impacts of EV and infrastructure deployment at continental scale. In our paper, we analyse the likely impact of related plans of the EU member states (MSs). With the help of qualitative and quantitative analyses, we study the impact of plans on recharging infrastructure deployment, contributions to the EU climate and energy goals, air quality objectives, and reinforcement of the EU's competitiveness and job creation. We soft-link a fleet impact model with a simplified source receptor relationship model, and propose a new model to calculate job impacts. The results overall show modest impacts by 2020, as most member states' plans are not very ambitious. According to our analysis of the plans, a reduction of CO_2 emissions by 0.4%, NO_x emissions by 0.37%, and $PM_{2.5}$ emissions by 0.44%, as well as a gross job creation of more than 8000 jobs will be achieved by 2020. The member state plans are very divergent. For countries with more ambitious targets up to 2020, such as Austria, France, Germany, and Luxemburg, the climate, energy, and air quality impacts are significant and show what would be achievable if the EU would increase its pace of EV and infrastructure deployment. We conclude that more ambitious efforts by the member states' to deploy electric vehicles could accelerate the reduction of CO_2 emissions and lead to less dependence on fossil oil-based fuels, along with air quality improvements, while at the same time creating new job opportunities in Europe. In regards to the ratio of publicly accessible recharging points (RPs) per EV, we conclude that member states have to come up with more ambitious targets for recharging point deployment, as the current plans will lead to only one recharging point per every 20 EVs by 2020 across the EU. This paper can serve as useful input to the further the planning of EV and recharging infrastructure deployment in the EU and elsewhere. Our study highlights that the different strategies that are followed in the EU member states can be a fertile ground to identify best practices. It remains a challenge to quantify how different support policies impact EV deployment. In terms of further research needs, we identify that more detailed studies are required to determine an appropriate level of infrastructure deployment, including fast chargers.

Keywords: alternative fuels; transport; electro-mobility; recharging and refuelling infrastructure; electric vehicles; greenhouse gas emissions; air pollutants; employment effects

1. Introduction

The European Union (EU) is committed to leading the global fight against climate change [1] and the long-term climate strategy of the European Commission (EC) shows how Europe can continue the way to a climate-neutral economy by 2050 [2]. In this context, the EU has the goal of reducing greenhouse gas (GHG) emissions from transport by at least 60% by 2050 compared with 1990, with an ambition to be firmly on the path towards zero-emission mobility by that time [3]. An important enabler to reaching these goals is switching to alternative lower carbon fuels, such as electricity, hydrogen, biofuels, or (bio)gas. As most of these alternative fuels (AFs) require a dedicated refuelling infrastructure, the EU has adopted the directive on the deployment of alternative fuel infrastructure (AFI) [4]. This is a reflection of the need for a synchronized deployment of alternative fuel vehicles (AFVs) and their related infrastructure, as highlighted in the literature. Hence, the intervention logic of the AFI directive is to overcome a failure of the market and provide appropriate recharging or refuelling infrastructure, synchronized with the deployment of AFVs and vice versa.

1.1. General Studies of Alternative Fuels and Infrastructure Interaction

Few papers have addressed the issue of the relationship between AFVs and AFIs. In [5], the case of sluggish deployment of compressed natural gas (CNG) vehicles in Germany was analysed. The most important reason identified was the failure to coordinate the complementary markets of the alternative fuel infrastructure with corresponding vehicles. For the US market, the success or failure of alternative fuel vehicle programmes and corresponding legislative policies was studied in [6]. It was concluded that a coordinated deployment of vehicles and refuelling infrastructure is essential for the successful deployment of alternative fuels in transport. The importance of broad stakeholder involvement in order to facilitate the transition was stressed. In [7], a literature review of consumer preferences for electric vehicles (EVs) was performed. The authors found that the density of recharging points (RPs) could positively affect the utility of EVs, a finding that is also echoed in the review of consumer preferences and interactions with EV recharging infrastructure from [8]. The importance of infrastructure as a success factor for deployment, in addition to costs and performance, was stressed in [9]. An indicator-based methodology for assessing the recharging infrastructure was developed in [10] for supporting its design and operation. The methodology is composed of eight indicators allowing a comparison of different publicly accessible recharging infrastructure networks. The indicators are: energy demand from the network, energy use intensity, charger intensity distribution, nearest neighbour distance and availability, use time ratio, energy use ratio, total service ratio, and carbon intensity of the infrastructure. While [10] is a promising approach to characterising recharging networks across different regions, some of its indicators rely on actual usage data and detailed geo-spatial information for the infrastructure. These data are, however, not readily available at the EU level. Hence, in our study, we focus on simpler indicators, such as the ratio of EVs per RPs, as well as RP density on road networks.

1.2. EV and Grid/Market Interaction

Several studies have addressed the challenges and opportunities of electrical power grids that the electrification of transport could bring, discussing the integration of electro-mobility into the smart grid context where recharging infrastructure serves as the interlinkage between EV fleets and power grids. They have analysed different strategies to minimise the negative grid impacts of EVs and minimise infrastructure investment needs. Controlled charging can stabilise the grid by valley filling and peak shaving [11]. Kong et al. [12] shows that increasing the available recharging infrastructure and EV plug-in durations can positively influence EV grid integration via load shift and vehicle-to-grid (V2G). Hernández et al. [13] stresses the important role of V2G in primary frequency control and dynamic grid support. Besides studying the potential role of EVs in the smart grid, [14] highlights the role that EVs can play as a voltage source in off-grid systems, or as an uninterruptible power supply in cases of grid power failures. In their study of a locational marginal pricing model, [15] concludes that dynamic energy pricing for the charging of electric vehicles can decrease costs considerably both for EV users as well as distribution system operators. Ruiz-Rodriguez et al. [16] and Hernández et al. [17] studied the interaction of photovoltaic generation and EVs in radial distribution systems. They used a probabilistic approach as a more robust method (rather than deterministic approaches) to ensure voltage constraint fulfilment in the design of distribution systems. In general, they concluded that the combined technical impact of photovoltaic generation and EV loads on radial distribution systems is lower than each one individually [17]. In a similar model-based assessment, [18] showed that biomass-fuelled gas engines as a renewable dispatchable generation source can further mitigate the technical grid impact of EV loads. Lopes et al. [19] and López et al. [20] stress the importance of EV aggregators in facilitating participation of EVs in the power market and V2G services. Studies regarding EV grid integration require detailed power modelling at high temporal and spatial resolution that go beyond the scope of our assessment.

1.3. EV Impacts

The potential impacts on GHG emissions of a larger deployment of EVs have been covered in numerous studies, which have employed multi-regional energy system models. See [21] for an overview which also highlights that most studies agree that the impact of EVs on GHG emissions is positive in most of the cases. Thiel et al. [22] have analysed the synergistic impact of the emission trading scheme and a future large-scale deployment of EVs on CO_2 emission reductions in the EU. In our assessment of the climate and energy impacts of the national policy frameworks (NPFs), we follow a similar energy system modelling-based approach as described in [21,22]. Schnell et al. [23] modelled the potential air quality impacts of EVs in the US and produced air pollutant concentration maps for the US with a spatial resolution of grid cells 50 × 50 km. Popa et al. [24] performed a similar study for hydrogen vehicles in Europe and published concentration maps of air pollutants with a spatial resolution comparable to [23]. Our assessment of the air quality impacts of the NPFs follows a similar methodological approach as [22,23], with a simplified source receptor model, but with a much more refined spatial resolution. We could not identify any publication that covers the direct job impacts of constructing, operating and maintaining recharging infrastructure.

As described above, assessment of infrastructure sufficiency [5–10] and certain impacts in isolation, such as GHG emissions, energy impacts and air quality, have been previously reported in the literature [11–24]. Our paper builds upon these earlier developed approaches and expands them further. The proposed methodology of this paper is novel, and a similar holistic, comprehensive assessment of AFI deployment plans across the entire EU, including job impacts, has to the knowledge of the authors never been performed before. The EU-wide air quality maps that this paper features, which respond to EV deployment scenarios, are at an unprecedented high spatial resolution level (roughly 7 × 7 km). The paper also compares the differences in ambition vis-à-vis EVs and related recharging infrastructure as expressed in the member states' plans and the originally proposed AFI directive. We analyse the associated impacts related to the different ambition levels and draw conclusions on how coordinated policies could increase the ambition levels for alternative fuel deployment in the EU.

The remainder of the paper is structured as follows: Section 2 introduces in more detail the policy context; Section 3 explains the assessment methodology; Section 4 discusses the results of the assessment; Section 5 concludes the paper and describes the main policy implications of the work.

2. Policy Context

The EU AFI directive [4] requires that EU member states (MSs) provide a minimum level of infrastructure for alternative fuels (AFs) in line with their expectations on future demand for those fuels. This minimum infrastructure coverage should enable the circulation of AFVs and vessels throughout the EU, including cross-border continuity. The directive covers the following alternative fuels and their related refuelling infrastructure: (i) electricity for road transport and stationary airplanes as well as shore-side electricity for vessels; (ii) natural gas for road transport and maritime ports as well as inland waterways; and (iii) hydrogen for road transport. The proposed directive [25] had foreseen concrete infrastructure deployment targets for publicly accessible RPs in MSs that were in accordance with the deployment of EVs expected at the time [26]. These concrete targets, which took into account motorisation and urbanisation rates in the MSs, were not retained in the adopted directive.

The AFI directive aims to facilitate a functional internal market for AFVs and technology, and infrastructure build-up [27]. According to the adopted directive, the MSs had to submit National Policy Frameworks (NPFs) to the European Commission. In their NPFs, the MSs had to outline their national targets and objectives for the deployment of the necessary infrastructure, as well as supporting actions for the development of a market in regards to AFs. The description of the current status of AFV and AFI deployment was a mandatory element of the NPFs. The MSs were requested to provide AFV estimates for the future in addition to their AFI targets, with a goal of establishing coherence between the two. The development of the NPFs led to significant scenario work in the different MSs. For example, in [28] it is described how the hydrogen-related part of the Italian NPF was developed. The EC then had to perform an assessment of the NPFs and their coherence at the EU level, including an evaluation of the level of attainment of national targets and objectives [27,29].

Figure 1 shows a schematic of the interaction of the different NPF elements. The NPFs describe the current statuses of AFV and AFI deployment, and establish future estimates and targets. In line with the status and future targets/estimates, the NPFs define support measures that should ensure that the targets are achieved. Typical support measures included in the NPFs were financial incentives for AFVs and AFI, legal requirements, access restrictions for conventional vehicles, removing administrative barriers for AFI deployment, and so on. The implementation of NPFs can result in the:

- creation of a recharging infrastructure across the EU MSs, including cross-border continuity and enabling a market deployment of electric vehicles;
- support to the attainment of EU climate and energy objectives;
- improvement of air quality;
- reinforcement of the EU's competitiveness and job creation.

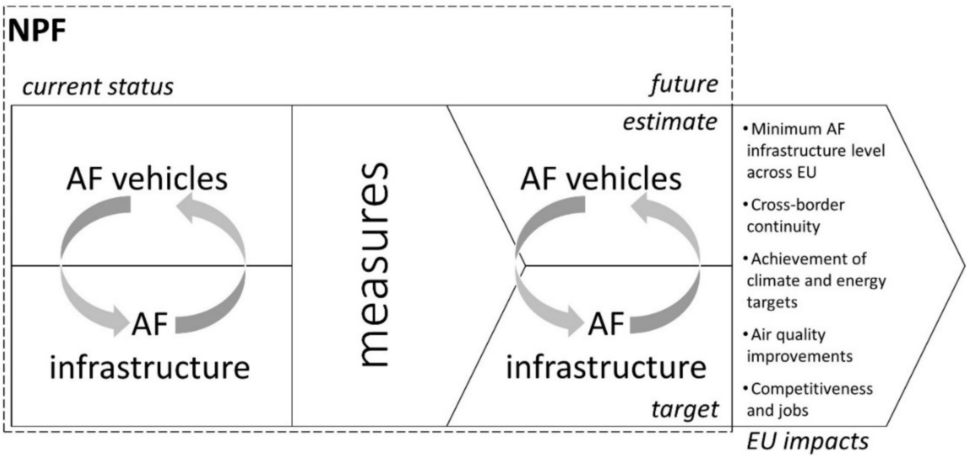


Figure 1. Interaction of NPF elements and EU-wide impacts. AF: alternative fuels, NPF: national policy framework. Source: [27].

These aspects were addressed during the NPF assessment. One result of the assessment report is that the ambition level of the individual NPFs and coherence at the EU level falls short of the original intention of the proposed AFI directive. While the full assessment report is documented in [27,29], documents to which the authors of this paper contributed with their analysis work, this paper extends the NPF assessment, focussing on the example of EVs and related infrastructure with the intention of informing the scientific community about the assessment and its methodology as well as discussing future research needs in this context.

3. Assessment Methodology

This section describes the methodology that was employed for assessing the EU-wide impacts of the NPFs: (i) creation of recharging infrastructure, (ii) contribution to EU climate and energy objectives, (iii) air quality impacts, and (iv) job impacts. Figure 2 provides a high-level overview of the different analytical methods that are employed in this paper and how they interact with each other. The basis for the assessment are the NPFs of the different MSs, which contain the current status and scenarios for EV and infrastructure deployment. In the recharging point sufficiency assessment, we calculate the ratio of EVs per RP for each member state and produce maps with infrastructure density and normalised difference indices (NDIs). The infrastructure deployment is taken as input for the job model which calculates gross job creation. The future projected EV shares from the MS NPFs are employed in the DIONE fleet impact model, which uses input from the PRIMES-TREMOVE model to ensure alignment with the general EU energy/transport projections that have been used for major EU policy initiatives, including the AFI directive [4]. DIONE results provide GHG and pollutant emissions as well as final energy demand for the road transport sector. The pollutant emissions resulting from the DIONE runs are then employed in the air quality model SHERPA (screening for high emission reduction on air), which produces air pollutant concentrations per modelled grid cell at a 7×7 km resolution. These results are then visualised as difference maps versus a reference scenario without NPFs (REF scenario).

More details for each method are described in the following subsections: Section 3.1, infrastructure sufficiency assessment; Section 3.2, energy/climate fleet impact model; Section 3.3, air quality model; Section 3.4, employment model; Section 3.5, scenario assumptions.

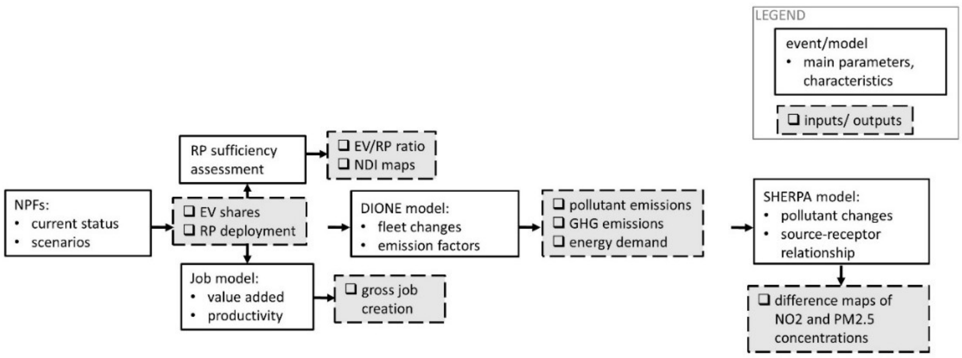


Figure 2. Overview of methodology. RP: recharging point, EV: electric vehicle, NO_2: nitrogen dioxide, PM2.5: particulate matter (diameter < 2.5 µm), NDI: normalised difference index.

Note that besides the assessment described in this paper, a number of checks were performed in order to verify compliance of the NPFs, point by point, with the requirements of the AFI directive. While this paper focuses on EVs and their related recharging infrastructure, the full assessment was performed for all fuels covered by the directive. The full assessment report also contains a semi-quantitative evaluation of the policy support measures that the MSs described in their NPFs. Full details are provided in [27,29]. In a counterfactual analysis, the authors also applied this assessment methodology to the targets of the originally proposed directive [25] in order to analyse the gap that remains between the original intended ambition and the one currently planned on the basis of the NPFs.

3.1. Creation of a Minimum Level of Recharging Infrastructure

In a first step, we assessed whether the NPF infrastructure targets can be considered sufficient within a given MS, vis-à-vis the expectations for the deployment of vehicles by the MS in its NPF. For RPs, the assessment follows a two-pronged approach by establishing minimum infrastructure criteria per number of vehicles on the one hand, and minimum distance requirements along the Trans-European Transport (TEN-T) core network on the other. The logic of this two-pronged approach is that (i) a minimum number of publicly accessible RPs is needed to remove consumer concerns vis-à-vis range and related infrastructure availability, and that (ii) sufficient infrastructure availability needs to be guaranteed along the main EU transport axes to enable free circulation of EVs across EU MSs. The applied criteria are one RP per estimated 10 electric vehicles and recharging stations at least every 60 km on the TEN-T core network [27,29].

In order to assess the coherence of infrastructure targets at the EU level, as required by article 10(2) of the AFI directive, a normalised difference index (NDI) was proposed as a measure of dissimilarity (see Equation (1)). It describes differences in infrastructure density between MSs. The NDI is calculated separately for each fuel and mode.

$$NDI = |I_n - I_m|/(I_n + I_m), \quad (1)$$

where NDI is the normalised difference index, I is the density of infrastructure (number of AFI/number of km of road (or inland waterway) network for a given MS) and n and m are the indexation of the MS (n, m = 1–28; n ≠ m).

Being a dissimilarity index, the NDI can have values between "0" when the density of infrastructure in two neighbouring MSs for a given fuel/mode is the same, and "1" in case of extreme difference when one MS-defined target and its neighbouring MS have a maximum dissimilarity. The higher the value of the NDI, the smaller the coherence between the neighbouring MSs in terms of targeted AFI density.

3.2. EU Climate and Energy Modelling

The first model linkage was done to calculate road transport energy use and emissions. To this end, the PRIMES-TREMOVE and the EC-owned DIONE (DIONE is a name and not an acronym) Fleet Impact model were used. Developed by the Energy-Economy-Environment Modelling Laboratory (E3MLab)/Institute of Communication and Computer Systems (ICCS) of the National Technical University of Athens, the PRIMES-TREMOVE energy economic model for the transport sector is a model for detailed projections and policy analysis (policy measures, emission reduction and costs) [30]. The model projects the evolution of demand for passengers and freight transport by transport mode and transport mean, based on the economic, utility and technology choices of consumers, and consequently projects the derived fuel consumption and emissions of pollutants. It is essentially a dynamic system of multi-agent choices under several constraints that are not necessarily binding simultaneously. The model consists of two main modules, the transport demand allocation module and the technology choice and equipment operation module [31]. The values of the variables "total vehicle stock" and "car travel activity" generated in PRIMES-TREMOVE were fed into DIONE. Since no values for ammonia (NH_3) and volatile organic compound (VOCs) emissions were available from PRIMES-TREMOVE, these were calculated in DIONE.

The DIONE model can be used to analyse fleet composition scenarios, related activity patterns, energy consumption and CO_2 as well as air pollutant emissions up to the year 2050. DIONE can assess transport and energy (policy) options (e.g., fleet emission targets, vehicle technology transition scenarios, different fuel mixes, etc.). Its core is a detailed description of vehicle types, their activities and efficiencies, which can then be flexibly adapted in scenario analyses. DIONE can be employed to run scenarios varying in vehicle stock, new registrations, survival rates, activity, efficiency, fuel pathways for well-to-wheel (WtW) energy consumption and emissions, biofuel admixture shares, and driving patterns [27].

For conventional vehicles, the energy and fuel consumption calculation in DIONE is based on the EMEP/EEA Air Pollutant Emission Inventory Guidebook [32]. For AFVs, an energy and emission calculation methodology has been developed that takes account of vehicle characteristics, trip lengths and speed distributions.

(1). Plug-in hybrid and range extender vehicles

For fuel consumption (FC), the FC factor (g of fuel) is derived as:

$$FICE(x,v) = x \times (a + c \times v + e \times v2)/(1 + b \times v + d \times v2) \quad (2)$$

for x > RANGEdynamic or FICE(x,v) = 0.

for x <= RANGEdynamic, where x is the distance travelled; v is the average velocity; and a, b, c, d, e and RANGEdynamic are vehicle-specific parameters. RANGEdynamic is a parameter related to the all-electric range, given by

$$\text{RANGEdynamic} = (\lambda \times \text{iSoC} + \mu) \times [1 - (\text{r3} \times (\text{v2}) - \text{r2} \times \text{v} + \text{r1})] \quad (3)$$

where r1, r2, r3, λ and μ are vehicle-specific parameters and iSoC is the initial state of charge of the battery for this trip.

For the battery electricity consumption (kWh), the factor used is equal to

$$\text{FBAT}(\text{x,v}) = \text{x} \times (\text{a1} + \text{c1} \times \text{v} + \text{e1} \times \text{v2}) \quad (4)$$

for x <= RANGEdynamic or

$$\text{FBAT}(\text{x,v}) = \lambda 1 \times \text{iSoC} + \mu 1 \quad (5)$$

for x > RANGEdynamic, where x is the distance travelled, v is the average velocity, iSoC is the initial state of charge of the battery for this trip (same as above) and a1, c1, e1, λ1 and μ1 are vehicle-specific battery related parameters. RANGEdynamic is the same parameter, provided above.

(2). Purely electric vehicles (battery and fuel cell electric vehicles)

These vehicles only use the battery for propulsion:

$$\text{FBAT}(\text{x,v}) = \text{x} \times \text{a} \quad (6)$$

where x is the distance travelled, and a is a vehicle-specific parameter. FBAT(x,v) is expressed in kWh for the BEV (battery electric vehicle).

DIONE has also been used for other impact assessments of the EC (e.g., [33]). Some of its modules are described in more detail in [34], while in [35,36] an overview on DIONE is provided.

In our modelling exercise, the following key climate and energy impacts were calculated in DIONE and summarised for 2020: CO_2 emissions, fossil oil use, NO_x and primary particulate matter (PPM) emissions.

3.3. Air Quality Modelling

The second model linkage was done to calculate the reductions in air pollutant emissions and concentrations. For this purpose, the DIONE and SHERPA (Screening for High Emission Reduction Potential on Air) models were used. The air quality improvements from the NPFs were assessed by using the air pollutant emission reductions, derived using the DIONE model, as input to the Commission-owned, open-access SHERPA model, to compute the resulting concentrations. In addition to the aforementioned NH_3, NO_x, PPM and VOC emissions, DIONE provided SHERPA with information on sulphur dioxide (SO_2) emissions.

SHERPA is based on simplified relationships between emissions and concentration levels [37], and can support local, regional and national authorities in the design and assessment of their air quality plans. It particularly helps to identify the most efficient administrative scale for potential actions in a multi-level governance decision context.

From the methodological point of view, SHERPA implements the concepts of "geographically weighted regression" or "local modelling approaches" [38] using "bell-shaped" kernel functions to define weighted local regressions between input (emissions) and output (concentrations). More formally, the concentration changes (ΔC_j, delta in comparison to the base case) in receptor cell "*j*" are computed as the sum of the changes due to emission changes (ΔE_i^p) emitted by any source cell "*i*" within the domain, and the considered precursors "*p*". So, the concentration delta in a receptor cell "*j*" can be computed as follows:

$$\Delta C_j = \sum_{p}^{N_{prec}} \sum_{i}^{N_{grid}} a_{ij}^{p} \Delta E_i^p \quad (7)$$

where N_{grid} is the number of grid cells within the domain, N_{prec} is the number of precursors, ΔE_i^p and ΔPM_j are the emission and concentration deltas, respectively, and a_{ij}^p are the unknown transfer coefficients between each source cell *i* and receptor cell *j*.

SHERPA formalizes the coefficients a_{ij}^p in the previous equation through a bell-shaped function. This bell-shaped function accounts for the variation in terms of distance, as follows:

$$a_{ij}^p = \alpha_j^p \left(1 + d_{ij}\right)^{-\omega_j^p} \quad (8)$$

where d_{ij} is the distance between a receptor cell "*j*" and source cell "*i*".

Therefore, the final formulation implemented in SHERPA is as follows:

$$\Delta C_j = \sum_{p}^{N_{prec}} \sum_{i}^{N_{grid}} \alpha_j^p \left(1 + d_{ij}\right)^{-\omega_j^p} \Delta E_i^p = \sum_{p}^{N_{prec}} \alpha_j^p \sum_{i}^{N_{grid}} \left(1 + d_{ij}\right)^{-\omega_j^p} \Delta E_i^p \quad (9)$$

where α_j^p and ω_j^p are the coefficients that define the SHERPA model, linking emission and concentration changes. These coefficients are estimated using the results of a set of simulations performed with a fully-fledged air quality model. The key idea is that, through least square regressions, and starting from the results (input and output) of a fully-fledged air quality model, it is possible to estimate the SHERPA model coefficients α_j^p and ω_j^p and use them to simulate, in a second stage, the impact of any emission reduction scenario on air quality. It is important to note that, in comparison with a fully-fledged air quality model, this is done in SHERPA in a more efficient way (in terms of computing time). More information on the SHERPA tool and the assumptions justifying this approach can be found also in [37,39]. SHERPA is currently publicly available with default EU-wide data for emissions and source-receptor relationships at a 7×7 km spatial resolution.

3.4. Job Impacts

A model has been developed to estimate the gross value creation and gross job impacts from the AFI deployment as targeted in the NPFs. It provides the effects resulting from infrastructure production, installation, operation and maintenance. It is adapted from a method used in [40] to calculate job impacts for renewable energy deployment in Europe. Our approach covers AFI for road transport (i.e., vehicle RPs, CNG and hydrogen refuelling points, as well as LNG refuelling points for heavy-duty vehicles).

The approach is sketched in Figure 3 for an exemplary MS (MS A) and normal power RPs. For each MS and infrastructure type the same process is carried out: AFI deployment targets are determined in a first step, then calculated as the NPF target number of recharging or refuelling points minus the number of the currently available infrastructure. The AFI deployment is assumed to be linear up to the target year. Added over MSs, the number of total planned AFI installations of each type for the whole EU is calculated. The net market prices per recharging/refuelling point are multiplied with the respective annual numbers of new AFI installed to calculate the gross value of RP production (GVP). As the market price of a technology includes all value added along the value chain, it is a reasonable proxy for the calculation of gross value of production added (GVA) [27,29].

In a second step, the share of MS A in the production and installation of AFI is determined. Imports from outside the EU are deducted. As the share of imported preliminary products differs among economic sectors, the GVP is sub-split. This is done by assigning the different technological components of an AFI installation (and thus their costs) to different economic sectors on the basis of data on the composition and prices of the different AFI types [27]. AFI GVP is assigned to the sectors shown in Table 1, in line with Eurostat NACE (statistical classification of economic activities in the European community; nomenclature statistique des activités économiques dans la communauté européenne) Revision 2 (statistical classification of economic activities, see https://ec.europa.eu/eurostat/web/nace-rev2).

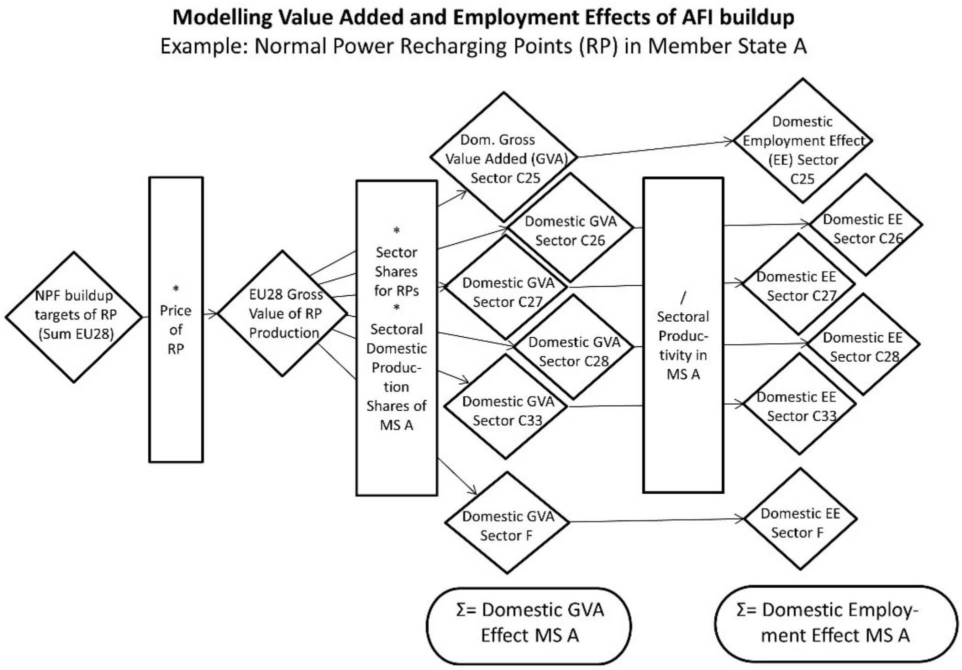


Figure 3. Flowchart of added value and employment calculation (adapted from [27]).

Table 1. Economic sectors contributing to RP production and installation (from [27]). NACE: nomenclature statistique des activités économiques dans la communauté européenne.

Sector	Fabricated Metal Products, except Machinery and Equipment	Computer, Electronic and Optical Products	Electrical Equipment	Machinery and Equipment	Repair and Installation Services of Machinery and Equipment	Constructions and Construction Works
NACE Sector Number	C25	C26	C27	C28	C33	F

For each of these sectors, the sectoral GVP is multiplied by the sectoral domestic production share, yielding the sectoral domestic gross value added (GVA) for each of the six sectors for the AFI type for MS A. By default, the sectoral domestic share in AFI production for each MS is assumed to be equal to that MS's present sectoral share of production value within the EU, which is derived from Eurostat data, assuming that the geographic distribution of RP production will be similar.

The national GVA effect resulting from RP production (sectors C25, C26, C27 and C28) is allocated completely (adjusted by preliminary imports) to the producing country. The costs of installing a recharging or refuelling point, occurring in sectors C33 and F, is divided into a GVA effect in the producing country and in the country that installs the infrastructure. An MS's domestic GVA effect from the particular infrastructure type is calculated as the sum of sectoral GVA effects across all sectors. AFI maintenance costs are included via a multiplier representing annual costs as a percentage of total investment per facility [27].

In a third step, the job impact of deploying a type of AFI in a given MS is derived from dividing the domestic GVA per economic sector by its productivity. This results in the number of years needed to build the AFI as targeted in the NPF. This again is assumed to convert into job impact. The productivity figures for each MS are derived by dividing the MS's sectoral GVA contributions to the AFI build-up by the number of employed persons in the same sector, with both data taken from Eurostat. The job impact calculation model is described in more detail in [27,29].

3.5. Scenario Assumptions

For the assessment, assumptions were made for the following three scenarios:

- REF scenario: The reference scenario without NPFs builds on the EU Reference Scenario 2016 [30], but excludes the incentives for alternative fuels provided at the MS level. The REF scenario was implemented in the PRIMES-TREMOVE model and replicated in the DIONE model (see Section 3.2).
- SWD2013 scenario: This scenario is based on the assumptions made in the impact assessment of the proposed AFI directive, as shown in the Staff Working Document (SWD) published in 2013 [26]. For the 2013 impact assessment, the PRIMES-TREMOVE model was used. This scenario was replicated in the DIONE model to calculate energy use and emission reductions from cars with respect to the other two scenarios.
- NPF scenario: This scenario is the result of taking into account the NPFs, submitted in 2016–2018 to the EC as per the adopted AFI directive. EV market uptake in the EU is lower under this scenario than under the SWD2013 scenario. The PRIMES-TREMOVE model was not used to run this scenario (see Section 3.2).

4. Assessment Results

This chapter shows some exemplary results of the assessment. The full assessment results and detailed NPF assessments are provided in [27,29]. Several NPFs did not address all the elements required by the AFI directive.

4.1. Recharging Infrastructure

Figure 4 shows the EVs on the road by 2020 as estimated in the different NPFs, and the number of EVs on the road in December 2017, in the different MSs. The figure compares these numbers with the assumptions that were made in the impact assessment accompanying the proposed AFI directive [26] SWD2013 scenario. The MSs are ordered from left to right by the number of EVs as assumed in the proposed directive (grey columns), starting with the highest number (in this case Germany). The figure reveals that only eight MSs estimated the same or higher EVs on the road by 2020 than assumed in the proposed directive, namely, Austria, Bulgaria, Denmark, France, Germany, Ireland, Luxembourg and Malta. Most of the MSs estimated lower EVs on the road when compared with the assumptions of the proposed directive. Several MSs did not provide any EV estimates for 2020, namely Croatia, Estonia, Romania and Sweden. For some of the MSs that have very ambitious estimates for 2020, it can be doubted that they will be reached as there is a big gap between the currently registered and future projected EVs. The time between the status in December 2017 as shown in Figure 4 and the end of 2020 is only three years and the policy measures implemented or planned seem not to be sufficient to boost deployment to levels that would be needed for the 2020 targets (for more details see [27,29]).

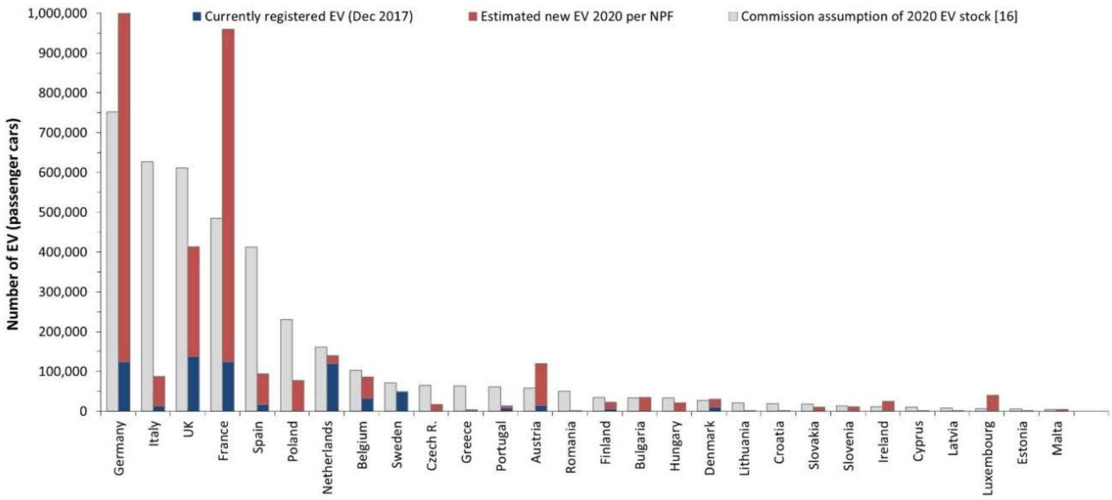


Figure 4. EV stock: existing and NPF estimates, compared with estimates from the proposed AFI directive for 2020 [25]. Data from [41] and the NPFs [26,29].

Figure 5 shows the number of RPs accessible to the public by 2020, as targeted in the different NPFs, and the number of those RPs already deployed in the different MSs at the end of 2017. The figure compares these numbers with the assumptions that were made for the proposed AFI directive [26] SWD2013 scenario. These assumptions included an expected stock of four million EVs in 2020, as well as an indicative ratio of one RP to 10 EVs.

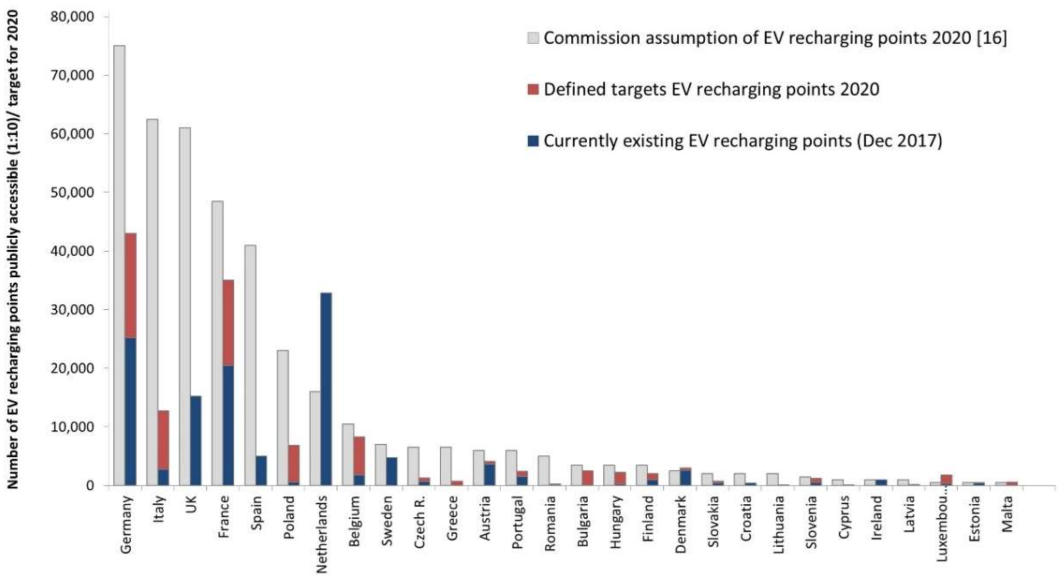


Figure 5. EV recharging points: existing and NPF targets, compared with targets from the proposed AFI directive for 2020 [25]. Data from [41] and the NPFs [26,29].

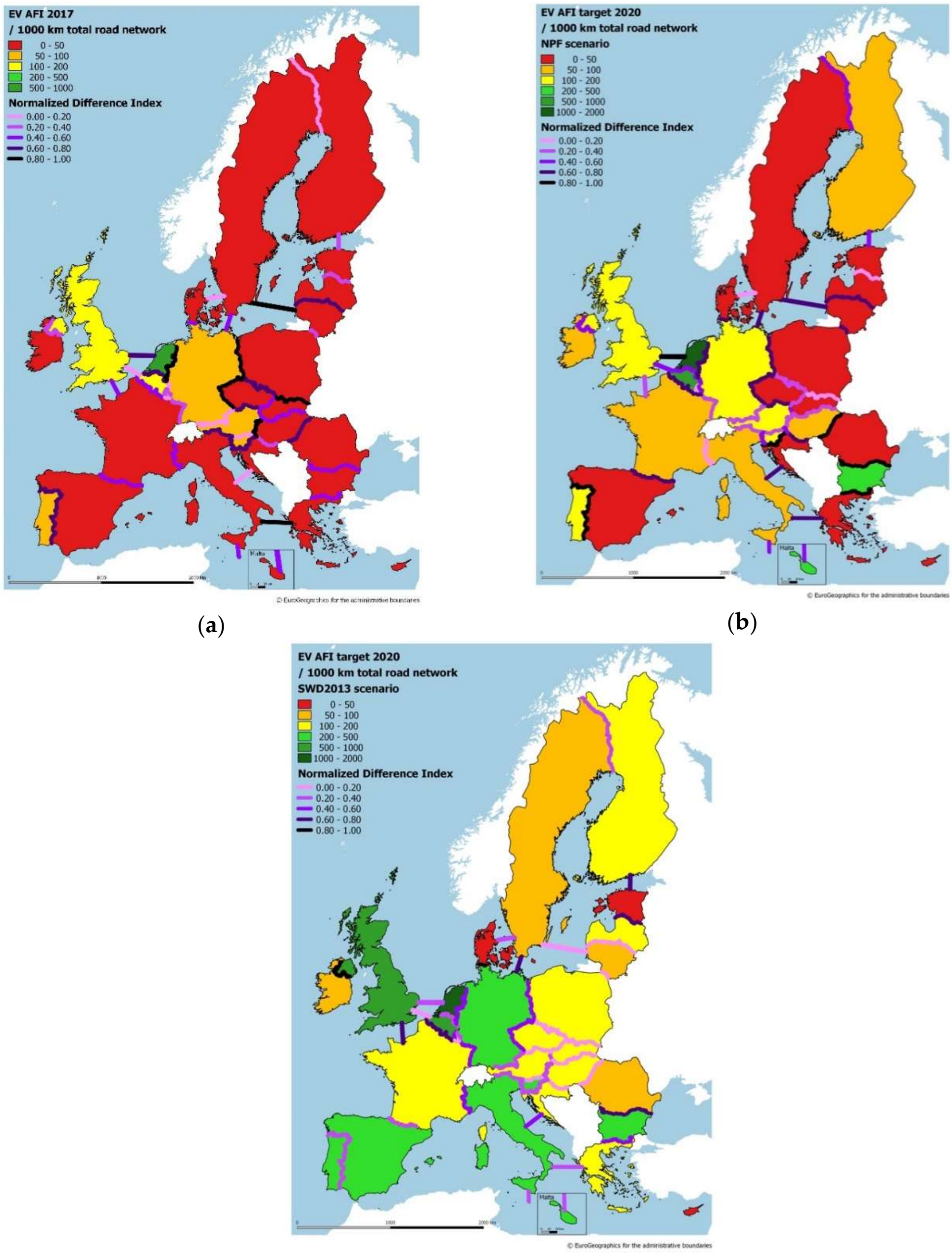
In [26], the total EV stock was distributed to each MS corresponding to the proportion of the MS car stock of the EU car stock, which was weighted by a factor indicating the MS share of urban population compared with the average EU one. The number of publicly accessible RPs required in each MS was computed according to this formula:

$$\begin{array}{c}\text{Number of publicly}\\ \text{accessible recharging}\\ \text{points needed}\ (\text{MS}_1)\end{array} = \frac{\text{Car stock}\ (\text{MS}_n)}{\begin{array}{c}\text{Car stock}\\ (\text{EU})\end{array}} \times \frac{\begin{array}{c}\text{Share of urban}\\ \text{population}\ (\text{MS}_n)\end{array}}{\begin{array}{c}\text{Share of urban}\\ \text{population}\ (\text{EU})\end{array}} \times \text{EV stock}(\text{EU}) \times \frac{1}{10} \quad (10)$$

The order of the MSs from left to right in Figure 5 follows the same order as in Figure 4. Figure 5 reveals that most of the MSs have established targets for publicly accessible RPs that are far below the targets that were foreseen in the proposed AFI directive. Only Denmark, Luxembourg and the Netherlands established targets that exceed the expectations of the proposed directive. Several MSs (Croatia, Ireland, Lithuania, the Netherlands and the UK) have already overachieved their 2020 targets by the end of 2017. Different from what was described above for the achievability of the projected EV numbers by end of 2020, the targets for RPs seem to be easily achievable for most MSs by end of 2020 or even before.

Figure 6 shows the current status of publicly accessible RP deployment for EVs, expressed in number of RPs per 1000 km of total road network length by MS, with 2020 targets based on the NPFs and the 2020 situation based on the assumptions underpinning the SWD2013 scenario [26]. The different values for the density of recharging infrastructure in Figure 5 are represented by applying a colour scale to the MS territories. Figure 6 also shows the results of the NDI calculations for these three cases through different coloured lines at the borders of the neighbouring MSs (NDI was introduced in Section 3.1 and Equation (1)). It can be positively noted that the MS NPFs target a growth of publicly accessible RPs, although falling significantly short of the numbers in the proposed AFI directive [26]. The Swedish and Spanish NPF did not contain 2020 targets for the number of RPs accessible to the public. Instead, Figure 6b shows 2017 data for these two countries. The results of the NDI calculations reveal rather incoherent levels of RP road densities between the MSs. The NDI between MSs with a common border or major ferry lines connecting them reaches values above 0.8 in some cases in our classification, corresponding to the highest level of incongruence. Based on the NPF targets, these high cases of incongruence are visible, for example, between Belgium and the UK, Bulgaria and Greece, Bulgaria and Romania, Croatia and Slovenia, Denmark and Germany, Hungary and Romania as well as Portugal and Spain. These incongruences could put one of the objectives of the AFI directive at risk, and must be amended to ensure cross-border continuity of AFI and hence enabling circulation of AFVs across MSs [4] (in this case exemplarily shown for EVs and related infrastructure). Figure 6c reveals a much higher congruence of RP road densities for the scenario SWD2013 of the proposed directive [26].

Figure 7 shows the status of EVs at the end of 2017 on the road globally [42] and in the EU (left axis) and compares this with the number of publicly accessible RPs in both regions (right axis). The two axes are aligned so that a ratio of one RP to 10 EVs would lead to the same height of the EV column (blue) as the RP column (green). The ratio of 1:10 is mentioned in recital 23 of the AFI directive as an indicative appropriate level of recharging infrastructure. In this respect, a level of less than 1:10 can be interpreted as a shortcoming in publicly accessible recharging infrastructure. At the end of 2017, the level of approximately 1:5 in the EU and 1:7 globally indicates in average more than sufficient availability of publicly accessible RPs when compared to the number of EVs on the road.



(**a**) (**b**) (**c**)

Figure 6. (**a**) Existing road EV AFI density and NDI; (**b**) 2020 target road EV AFI density and NDI (NPF scenario); (**c**) 2020 target road EV AFI density and NDI (SWD2013 scenario). Malta enlarged. Data from [41] and the NPFs [26,29].

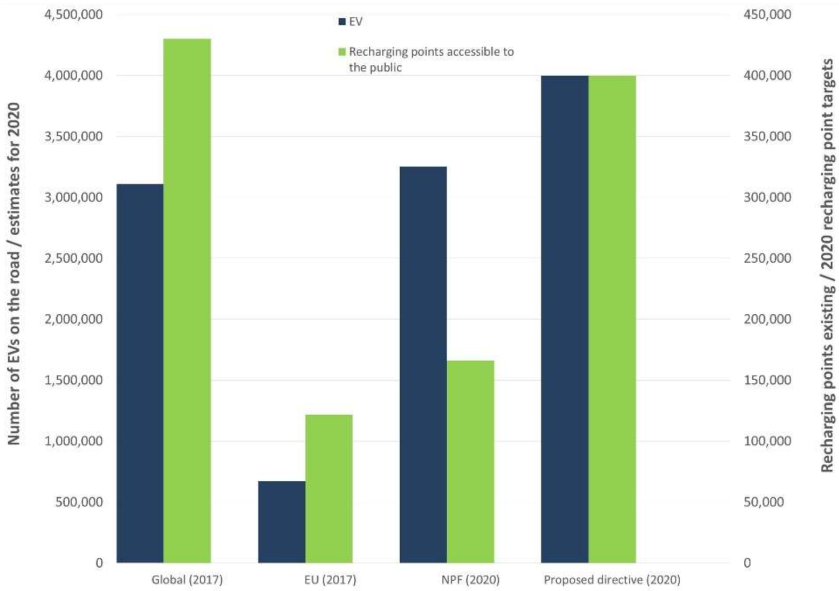


Figure 7. EV (left axis) and recharging infrastructure (right axis) deployment: global, EU, NPF and proposed AFI directive estimates and targets. Data from [41,42] and the NPFs [26,29].

Figure 7 also shows the situation in 2020 according to the NPFs and EC assumptions from the proposed directive [26]. It can be noticed that in the NPFs case, the ratio will significantly deteriorate by 2020. If the NPF targets are reached and the EV estimates materialise, the resulting ratio of approximately one publicly accessible RP per 20 EVs would be largely insufficient.

4.2. Climate and Energy Impacts

Based on the method described in Section 3.2, the scenarios as described in Section 3.5 and employing Equations (2)–(6) for the electrified vehicles, the climate and energy impacts were calculated. Altogether, the assessment of the NPFs revealed a rather low ambition level in terms of AFVs and vessels and the corresponding recharging and refuelling infrastructure as foreseen by most MSs. This rather low ambition level also translated into rather low impacts in terms of energy and emissions reduction. According to the impact calculations that were done on the basis of the estimated deployment of EVs, the following impacts were derived for an EU level for the year 2020 (see Table 2). In line with the descriptions provided in Sections 3.2 and 3.5, reductions in fossil oil use and emissions were determined firstly for the NPF scenario versus the REF scenario, and secondly for the SWD2013 scenario versus the NPF scenario. Overall, the reduction in energy and emissions is higher when the comparison is made between the scenario based on the proposed AFI directive (SWD2013) and the reference scenario without NPFs (REF) than when it is made between the NPF scenario and the REF scenario. The reduction in fossil oil-based fuels and related CO_2 emissions is approximately 0.6% under the proposed directive, with respect to the REF scenario. For NO_x emissions it is 0.46%, and for $PM_{2.5}$ emissions it is 0.55%. In any case, the time frame until 2020 is rather short and higher impacts can be expected beyond 2020 when more EVs are deployed.

Table 2. Oil demand and tank-to-wheel emissions impacts in the EU28 (2020), by scenario. REF: reference scenario, SWD2013: staff working document [26].

Impact in the Transport Sector	NPF vs. REF *	SWD2013 ** vs. NPF
Reduction of fossil oil-based fuels and related CO_2 emissions	0.4%	0.2%
Reduction of NO_x emissions	0.37%	0.09%
Reduction of $PM_{2.5}$ emissions	0.44%	0.11%

* Reference scenario without NPFs. ** Scenario based on the proposed AFI directive [26].

Figure 8 shows the changes in EV stock versus CO_2 emissions between scenarios in 2020 for the 16 MSs that communicated less ambition in their NPF EV estimates than the ones of the SWD2013 scenario. The reductions in CO_2 emissions at the MS level are rather modest, which is in line with the EU number from Table 2. Only Greece and Cyprus have values that exceed 0.8% CO_2 emissions reduction for 2020. With similar EV stock change values to Cyprus, the estimated CO_2 emission reduction percentage for Latvia is rather low. This can be explained by the fact that EVs represent only 1.2% of total stock in Latvia, compared to 1.9% in Cyprus.

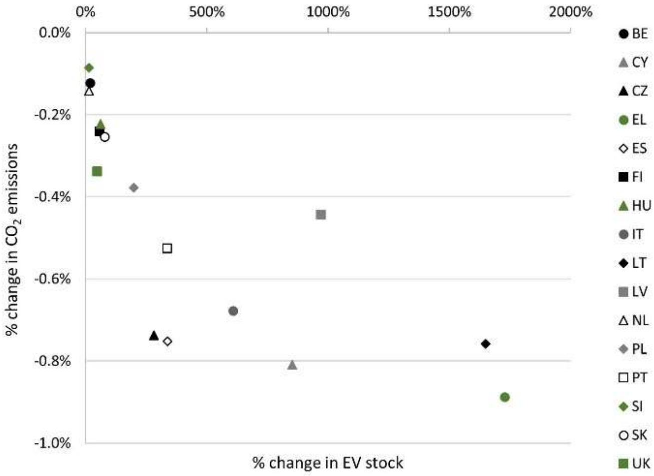


Figure 8. EV stock and CO_2 emissions in 2020: SWD2013 scenario vs. NPF scenario. Data from the NPFs [26,29].

4.3. Air Quality Impacts

In this section, we show the results of the combined DIONE/SHERPA runs for air quality improvements. As previously explained, DIONE is used to compute emissions (for NO_x, VOC, NH_3, PPM and SO_2) due to a given scenario, and then SHERPA is applied to compute the resulting air pollutant concentrations. The SHERPA model is implemented through the aforementioned Equations (7)–(9), converting emissions to concentration changes and focusing on the differences in comparison to the REF and SWD2013 scenarios.

Figure 9 shows the results of the combined DIONE/SHERPA runs for air quality improvements that could be achieved in the EU by 2020 on the basis of its NPF estimates and targets. Austria, France, Germany and Luxembourg are the MSs that each feature an NPF with a relatively high ambition level for 2020. Figure 9 reveals how the ambition in terms of AF deployment can translate into significant air quality improvements in terms of NO_2 and $PM_{2.5}$ concentrations in these MSs. It can be positively noted that the improvements are highest in urban and suburban agglomerations, where air quality issues are typically more severe and affect a more densely concentrated population. The charts also show how other MSs could profit from more ambitious plans, as expressed in the maps that display the difference between the assumptions of the proposed AFI directive [26] and the 2020 NPF values. In particular, Croatia, Czech Republic, Estonia, Greece, Italy, Latvia, Lithuania, Portugal, Romania, Spain and Sweden could improve their air quality levels as a result of higher EV deployment ambition. For $PM_{2.5}$, the improvement would be more significant in urban agglomerations, such as Madrid, Prague, Rome and the densely populated Po valley in the north of Italy.

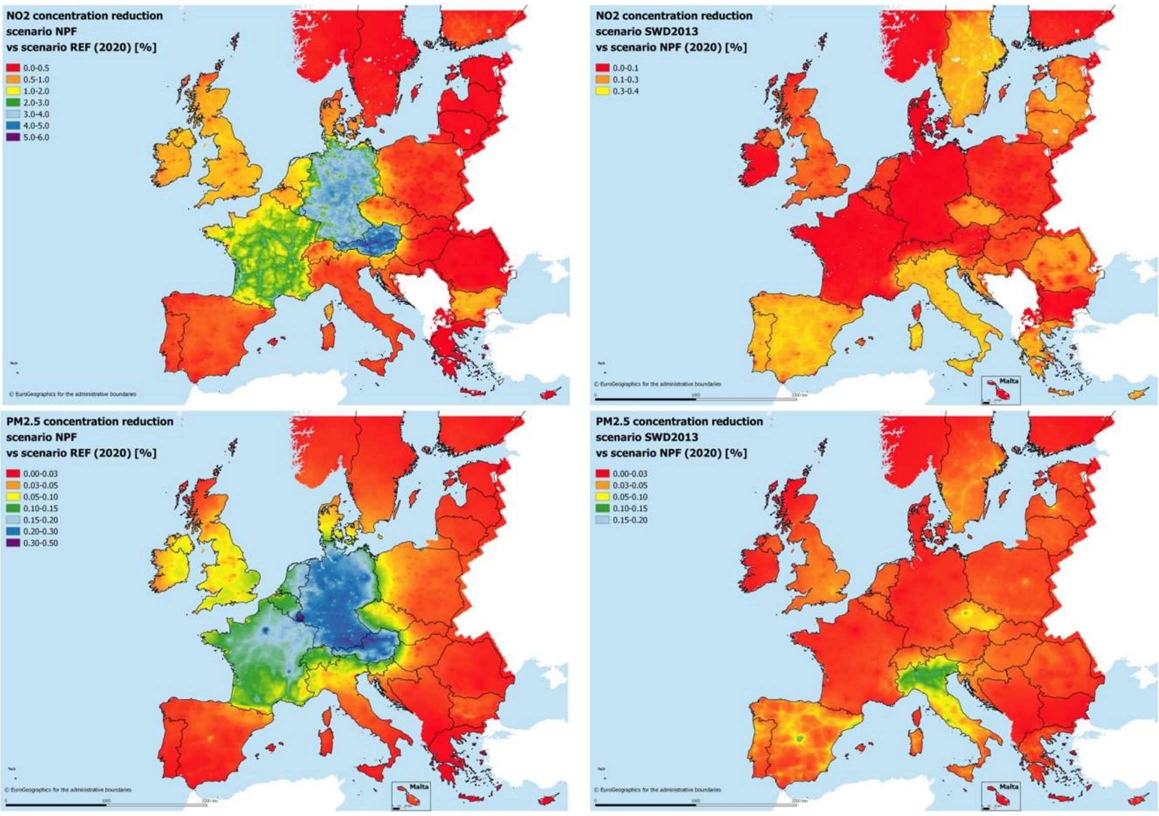


Figure 9. 2020 concentration reductions (%) in NO_2 (**upper row**) and $PM_{2.5}$ (**lower row**) (in the NPF scenario vs. the REF scenario (**left**) and in the SWD2013 scenario vs. the NPF scenario (**right**)). Malta enlarged. Source: values from the NPFs [26,29], upper row adapted from [43].

4.4. Job Impacts

Figure 10 shows the direct gross job impacts that can be generated as a result of the build-up, maintenance and operation of AFI in the EU, according to the NPF targets, calculated using the employment model described in Section 3.4. According to our quantitative analysis, a few thousand additional jobs could be created through AFI resulting from the NPFs, slightly increasing from 2017 to 2020. Beyond 2020, development will strongly depend on whether the momentum for further AFI deployment will be sustained in the long term. The calculated job impact numbers only consider publicly accessible infrastructure and as such exclude additional impacts that could result, for example, from the installation of private RPs.

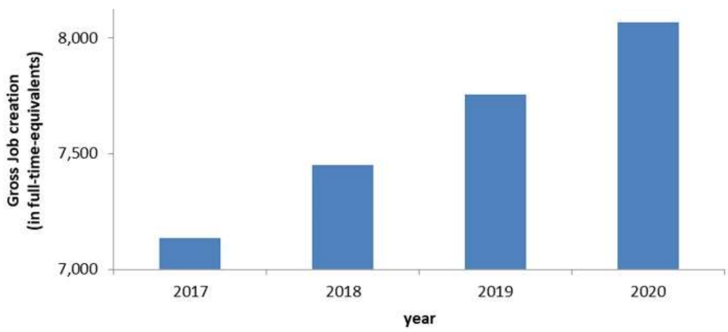


Figure 10. Gross job creation through infrastructure build-up, operation and maintenance (2017–2020).

Figure 11 specifies the direct employment impacts by EU member state, which can be up to around 1500 full-time jobs per year in Germany, followed by roughly 800 in Italy, 700 in France and around

400 in Poland and the UK. These impacts result from the additional economic activity in the sectors involved in AFI production, installation and maintenance. Another 1000 full-time jobs annually are created in the sectors providing preliminary inputs within the EU, which are not shown in Figure 11. These projections are based on the assumption that AFI production will be distributed among EU member states proportionally to the present geographic distribution of economic activities in the sectors involved, and that present productivities in the sectors and member states involved will apply for AFI related activities as well.

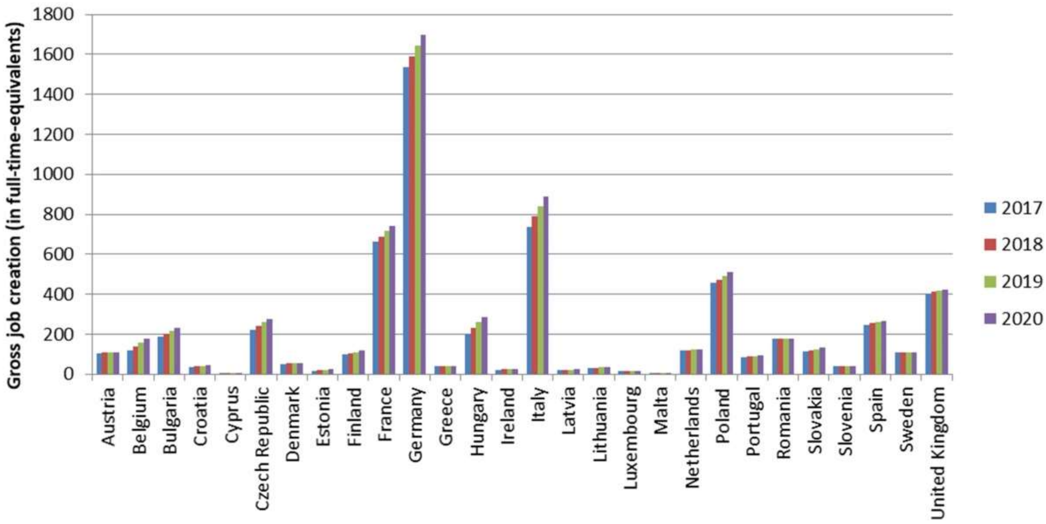


Figure 11. Direct gross job creation through infrastructure build-up, operation and maintenance per EU member state (2017–2020).

Figure 12 shows the job creation split by manufacturing of components (aggregation of sectors C25, C26, C27 and C28; see Table 1 for details), installation and maintenance (aggregation of sectors C33 and F) and preliminary production in the EU related to AFI from 2017 to 2020. The largest absolute employment increase of 3500 full-time equivalents annually occurs in component manufacturing. This is constant over time, due to the assumed linear build-up of infrastructure to reach the 2020 target. The second largest contribution, growing from 2400 to 3200 full-time equivalents, comes from installation and maintenance, the latter of which increases with stock. Roughly a thousand jobs are created in preliminary production throughout the EU, which is also constant from 2017 to 2020 because of the above-mentioned assumption of a linear infrastructure build-up during those years.

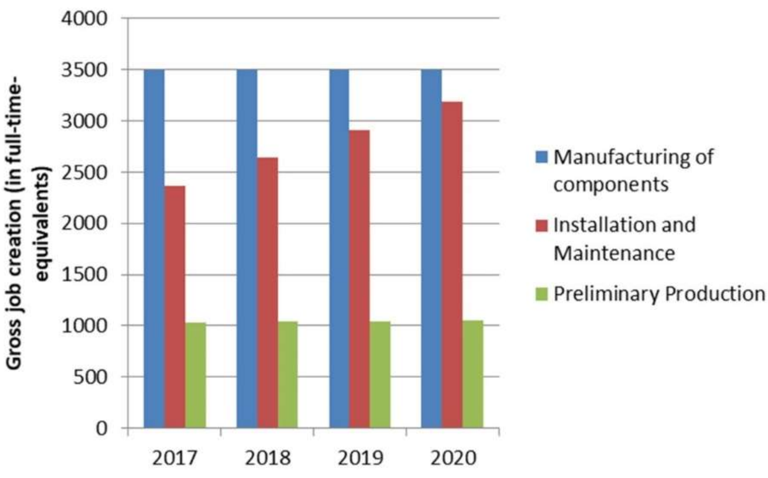


Figure 12. Gross job creation split by activities (2017–2020).

5. Conclusions and Policy Implications

With the directive on the deployment of AFI [4], the EU aims to address the chicken-and-egg problem of the simultaneous deployment of AFVs and vessels and their corresponding recharging/refuelling infrastructure. The AFI directive's implementation is in progress, amongst others, through the establishment and implementation of NPFs in the MSs. At the beginning of 2019, the EC started the process of evaluating the directive and assessing its implementation and effectiveness in view of a possible future revision.

To sum up, we developed for the first time a methodology to comprehensively assess the fulfilment of the requirements of the AFI directive and the coherence of the NPFs at the EU level. To this end, four key performance indicators were considered: (i) creation of a recharging infrastructure across the EU MSs, including cross-border continuity and enabling the market deployment of electric vehicles; (ii) contribution to the EU climate and energy goals; (iii) air quality objectives; and (iv) reinforcement of the EU's competitiveness and job creation. To quantify these impacts, a modelling exercise comprising the soft-linking of three models (PRIMES-TREMOVE, DIONE and SHERPA; see [43] for a detailed description of this exercise) was undertaken. In addition, a job impact model was developed. This methodology was applied to three scenarios: (i) a reference scenario without NPFs; (ii) a scenario based on the originally proposed directive, which was more ambitious than the NPFs; and (iii) a scenario based on the NPFs notified by the EC as per the adopted directive.

As a result of this research, we conclude that the level of ambition and coherence of the NPFs for the various fuel/mode options that are addressed in the AFI directive is low. All NPFs combined would lead to only 1.2% EVs of total passenger car stock in the EU by 2020. This low share is accompanied by a very big divergence across MSs, with ranges of below 0.1% (Greece) to more than 9% (Luxembourg) by 2020. For the ratio of publicly accessible RPs per EVs, the NPF targets lead to ranges between 1:29 (United Kingdom) and 1:3 (Latvia) by 2020. According to our analysis, for 2020, this will result in a ratio of one publicly accessible RP per 20 EVs EU-wide, which is far below the intention of the AFI directive (one RP per 10 EVs). The key policy implication of our work is that further action is required to accelerate the deployment of AFI in the EU. Member states need to reinforce their efforts to ensure that a sufficient number of publicly accessible RPs are deployed by 2020. This could be performed through the form of incentives for the build-up of RPs, and would probably have to be accompanied with support measures for EVs as long as their total cost of ownership is not at an equal level to the one for comparable conventional cars. To this end, and as a result of the assessment described in this paper, the EC has adopted an Action Plan on Alternative Fuels Infrastructure [44] that highlights actions to complement and better implement the NPFs to help create an EU backbone infrastructure by 2025.

Nevertheless, this first iteration of submission and assessment of NPFs is a good start, as it can be used as a basis to work on a common vision for alternative fuels in the EU, and can be an important enabler for broader EU energy and climate, air quality and competitiveness policy goals. We show, for the example of EVs and related infrastructure, that their deployment can already have positive impacts by 2020, albeit small because of the low ambition level of the NPFs, for all of these societal dimensions. According to our analysis, by 2020 the NPFs will lead to an EU-wide reduction of CO_2 emissions by 0.4%, NO_x emissions by 0.37% and $PM_{2.5}$ emissions by 0.44%, as well as a gross job creation of more than 8000 jobs for the build-up, operation and maintenance of recharging infrastructure. In order to speed up the transition towards low and zero emission mobility, it is important to use the 2020 NPF targets as a starting point for more ambitious deployment targets towards 2030 and beyond. It would be essential that MSs establish congruent plans and impactful support measures to accelerate the deployment of a synchronised EV and infrastructure deployment. It will be crucial to avoid a lack of publicly accessible recharging infrastructure, which would result in a limiting factor for the further EV market deployment. Coordination and cooperation of MSs needs to be stepped up in order to ensure cross-border continuity of AFI and the possibility for AFV to circulate without barriers across MSs. The establishment and use of a detailed common template for the MSs' reporting on the implementation of the NPFs could greatly facilitate future assessments and regular monitoring of the progress towards higher levels of alternative fuel use in transport.

Major limitations of our study are linked to the development of scenarios, as it proves difficult to disentangle the effects of different policies that can all have an influence on EV deployment. For example, the CO_2 regulation for cars [45] could possibly have a greater effect on EV deployment than the AFI directive [46]. When the aim of the analysis is to estimate the impact of recharging infrastructure development on the deployment of EVs, it thus proves difficult to design a scenario that captures well the mechanisms of the associated infrastructure support measures. In general, more research is needed to quantify the effect of support measures on EV and infrastructure deployment. The EU efforts, and especially their variation in the different member states, can in this context be considered a giant living laboratory experiment, and future research can perform ex-post analyses on the observed deployment due to the different support regimes in the MSs. In future research activities, the employment effects of EV and infrastructure deployment could be studied in more detail, going beyond the narrow scope of direct gross employment effects for recharging point deployment that has been used in this paper. In general, more research is needed for the "right-sizing" of a recharging infrastructure accessible to the public. More evidence from the field should be gathered to identify from which levels infrastructure becomes a limiting factor for EV deployment. This includes the necessity of a network of fast chargers. The authors invite the readers to provide their feedback and additional suggestions regarding the assessment methodology and further research needs.

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Abbreviations

AF	alternative fuels
AFI	alternative fuels infrastructure
AFV	alternative fuels vehicle
BAT	battery
CNG	compressed natural gas
CO_2	carbon dioxide
DIONE	fleet impact model, (DIONE is a name not an acronym)
E3MLab	Energy-Economy-Environment Modelling Laboratory
EC	European Commission
EE	employment effect
EU	European Union
EV	electric vehicle
GHG	greenhouse gas
GVA	gross value of production added
GVP	gross value of production
ICCS	Institute of Communication and Computer Systems
ICE	internal combustion engine
JRC	Joint Research Centre
LNG	liquefied natural gas
MS	member state

NACE	nomenclature statistique des activités économiques dans la communauté Européenne
NDI	normalised difference index
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NPF	national policy framework
PM	particulate matter ($PM_{2.5}$ is PM with a diameter of 2.5 μm or less)
PPM	primary particulate matter
PRIMES-TREMOVE	price-induced market equilibrium system (linked with transport model)
REF	reference scenario
RP	recharging point
SHERPA	screening for high emission reduction on air model
SWD	staff working document
TEN-T	Trans-European Transport Network
UK	United Kingdom
US	United States
VOC	volatile organic compounds
WtW	well-to-wheel

Formula Parameters and Variables

Infrastructure NDI	
Index	density of infrastructure
m, n	member state index
DIONE	
a,b,c,d,e	vehicle specific parameters
a1, c1, e1, λ1, μ1	vehicle specific battery related parameters
F, FC	fuel consumption
iSOC	intial state of charge (of the battery)
r1, r2, r3, λ, μ	vehicle specific parameters
$RANGE_{dynamic}$	all-electric range of a plug-in hybrid vehicle or range extender vehicle
v	velocity
x	distance travelled
SHERPA	
ΔE	change in emissions (in comparison to the base case) due to a given policy
ΔC	change in average concentrations (in comparison to the base case) due to a given policy
i, j	source and receptor cells
N_{grid}	total number of source cells
p	considered precursor emissions (NO_x, VOC, NH_3, PPM, SO_2)
N_{prec}	total number of precursors
NO_x	yearly emissions of nitrogen oxides
VOC	yearly emissions of volatile organic compounds
NH_3	yearly emissions of ammonia
PPM	yearly emissions of primary particulate matter
SO_2	yearly emissions of sulphur dioxide
NO_2	yearly average concentrations of nitrogen dioxides
$PM_{2.5}$	yearly average concentrations of particulate matter (diameter < 2.5 μm)
a_{ij}^p	SHERPA transfer coefficients (general formulation)
α_j^p, ω_j^p	SHERPA transfer coefficients (specific formulation)
d_{ij}	distances between sources (i) and receptors (j)

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