Agent-based model and service-oriented architecture for shifting from consumer to prosumer e-mobility behaviors in flex community

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Abstract
The energy market is rapidly transforming and so is the role of the consumer. As new prosumers, energy markets can benefit from their generation, consumption, and storage capabilities. The H2020 REDREAM project develops a strategy for the creation of a value generation chain based on a revolutionary service-dominant logic in which services are exchanged. Mobility service is one of the non-energy services of REDREAM. It enables to compute key indicators, such as energy consumption and CO2 emission, related to mobility behaviors for each prosumer, using different means of transport, including green ones. This paper presents the general architecture and the agent-based models that are included in the mobility service. A brief comparison of the mobility service to other mapping libraries is provided. Experiments with 400 real prosumers constitute the next step of this on-going work.

Keywords: *Mobility behavior, Energy Consumption, CO2 Emission, User-centric approach, Agent-based modeling.*

I. INTRODUCTION

The energy market is rapidly transforming and so is the role of the consumer. Yesterday's passive consumers are central actors in today's energy markets. As new prosumers, energy markets can benefit from their generation, consumption, and storage capabilities. The EU-funded REDREAM[1] project enables the effective participation of consumers and prosumers in the energy market. The project develops a strategy for the creation of a value generation chain based on a revolutionary service-dominant logic in which services are exchanged. The project fosters the demand response tools and energy and non-energy services that enable consumers to participate in the energy market. This will lead to the establishment of a new concept: a connected user-centered energy ecosystem.

Mobility service is one of the non-energy services of the REDREAM ecosystem. It enables to compute key indicators, such as energy consumption and CO2 emission, related to mobility behaviors using different means of transport, including green ones. In the REDREAM ecosystem, the mobility service is part of the "non-energy tools" in Layer 5 on Figure 1**Erreur ! Source du renvoi introuvable.**. The mobility service is driven by the data obtained from the prosumers that want to share it and from external data sources such as public road and vehicles databases. The collected information is stored in the mobility service's cloud and analyzed to provide global and community indicators to the user tools. The service considers vehicles whatever is the type (car, bus, shuttle, bike…) and whatever is their propulsion system (fuel, gas, electric…), but also pedestrian mobility. One of the goals is to evaluate energy consumption and reproduce the plug-in and plug-out event to Electric Charging Point (ECP) and virtualize what would have been the more efficient mobility scenario, including alternative paths which are more energy-efficient as well as faster.

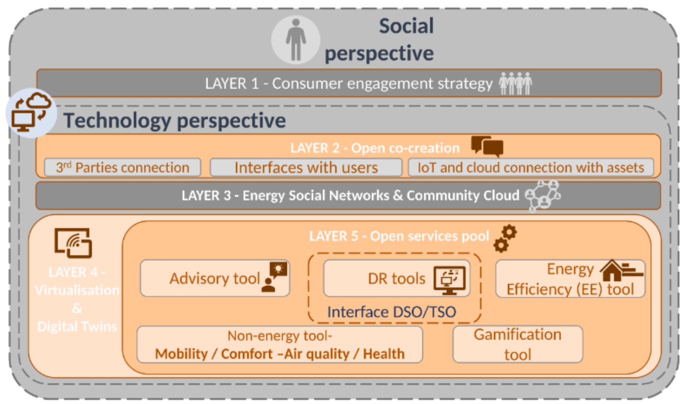

Figure 1. Layers and modules of the REDREAM Ecosystem

This paper presents the first results of the ongoing definition of the REDREAM mobility service. The major features of the mobility service are related to the simulation of vehicle mobility, support of ECP and their events, evaluation of the energy consumption and CO2 emissions related to the mobility activities of the prosumers that are represents their mobility behavior, and the computation and providing of global and community indicators. The mobility service design is based on

[1] https://redream-energy-network.eu/

the agent-oriented paradigm **[1]** and standards of the service-based software (SOA).

This paper presents the first design and implementation results related to the agent-based and service-oriented architecture of the mobility service. These results will be deployed in four demo sites at EU scale during the coming months for validating the contributions of the mobility service to the gamification and community portals of the project.

This paper is structured as follows. Section II provides a general description of the mobility service architecture. Section III provides the agent-based models that are included in the mobility service. Section IV gives several details on the four demo sites. Section V compares the mobility service to other mapping libraries.

II. General Architecture

According to D1.6, mobility simulation and virtualization are driven by the data obtained from the prosumers that want to share it and from external data sources such as public road and vehicles databases. The collected information is stored in the mobility service's cloud, i.e., in a dedicated database, and analyzed to provide global and community indicators. The mobility service considers vehicles whatever is the type (car, bus, shuttle, bike…) and whatever is their propulsion system (fuel, gas, electric…), but also pedestrian mobility. One of the goals is to evaluate energy consumption and reproduce the plug-in and plug-out event to ECP and virtualize what would have been the more efficient scenario. The mobility simulation extracts, from prosumers, insights that determine mobility behavior. They also simulate vehicles and pedestrian mobility to show alternative paths to users who are more energy efficient as well as faster.

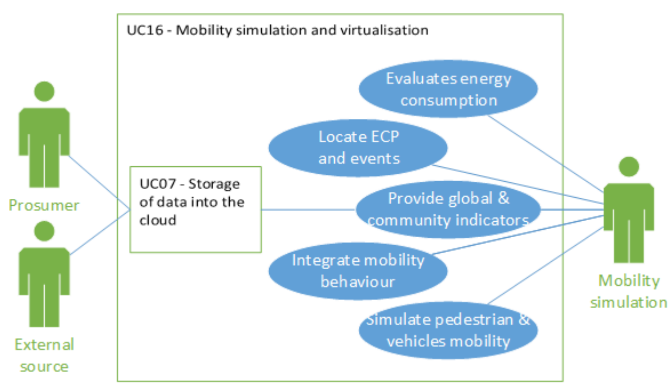

Figure 2. Use case diagram for the mobility service

The mobility service has the role of providing a simulation infrastructure for forecasting the impact of mobility on energy consumption and charging, and gas emission. It means that the mobility service will evaluate the: *(i)* the quantity of energy (liters of gasoline, watts for electricity) that is consumed by the mobility mean used by the prosumer depending on the daily travel behavior of this prosumer; *(ii)* consumption of energy at home for charging Electric Vehicles (EV) when it is plugged on ECP; *(iii)* emission of CO2 gas by the mean of transport (excluding EV that is assumed to not emit CO2). The simulation scenarios are defined at the end of this report. According to the REDREAM architecture, the mobility service will be accessible through RESTFUL services.

To include multiple parameters at different levels, a microscopic simulator of mobility is created. The selected modelling and simulation paradigms are related to multiagent systems (MAS) because they enable the simulation of individuals, their interactions, and their complex environment. In this way, the mobility service:

- *"Simulate pedestrian & vehicle mobility":* The service simulates the mobility behavior of the prosumers for all modes and types of transportation (walk, car, bus, shuttle, bike) and all types of engines (fuel, gas, electric) used. To simulate the prosumer mobility, an environment must be defined. It is composed of the roads, mobility infrastructure, and ECP that should be included in the simulation scenarios.
- *"Locate ECP and events":* ECPs are necessary for charging the EV. Because electric mobility is simulated by the mobility service, ECP must be included in the knowledge database of the service. Each ECP generates plug-in and plug-out events when EV is connected and disconnected. These events are used by the mobility service to determine the EV charging profile (when plugged in) or the EV consumption (when plugged out).
- *"Evaluate energy consumption":* The mobility service evaluates the energy consumption of the transport modes that are used by the prosumers. The service also evaluates EV electric consumption (cars, bikes, scooters) according to their consumption curves. Energy consumption of fossil-based energy vehicles is also evaluated and integrated into the trip's computation and the associated costs. CO2 gas emission for all the types of vehicles will be evaluated based on the trips that are given by the prosumer.
- *"Integrate mobility behavior":* The mobility service integrates the prosumer's mobility behavior in the form of daily or weekly trips. A trip is defined by a sequence of at least two spatial points (usually expressed by GPS

coordinates), with departure time windows or the expected arrival time windows.

- *“Provide global and community indicators”:* In addition to the user-centric and trip-based indicators provided by the mobility service, the mobility service provides key indicators that are related to the global mobility behavior of the prosumer. These global indicators could be used by the other service in the REDREAM ecosystem to set up a gamification application or publish them on a community portal.

III. Agent-Based Vehicle Models

According to the MAS approach, a model of the environment should be defined. In the REDREAM ecosystem, the HERE mapping system is used. HERE can compute the energy consumption of each vehicle based on specific vehicle-specific parameters, which are then used to calculate energy consumption for the vehicle on a given route. One challenge in the context of the REDREAM project is to define the values of the equation parameters to represent the supported types of vehicles and adapted to the behavior of each prosumer. To select the best values for the equation parameters, a review of scientific papers and existing reports from Canada and EU institutions have been conducted. The sources have been selected because they are recent, and that is important for EV data. They are mentioned for each type of model. However, it is important to note that there is no open-access database that stores all the parameters that were found in the downloaded documents. According to your knowledge, manual analysis of the different sources must be still done by hand.

3.1. Generic Energy Consumption Model

Equation for energy consumption of any vehicle is defined in Eq. 1:

$$C = P_{asc} \times \Delta h_{+} + P_{desc} \times \Delta h_{-} + P_{speed} \times L + P_{aux} \times t \quad (1)$$

Consumption *C* along the road segment depends on the length, speed, and elevation difference of the roads. Parameters are described in

Table 1.

Table 1. Parameters of the energy consumption equation

Model Parameter	Description
P_{asc}	Energy consumed per meter rise in elevation
P_{desc}	Energy recovered per meter fall in elevation.
P_{speed}	Function curve specifying consumption rate at a given free or traffic flow speed on a flat stretch of road. Consumption speed tables define the energy consumption rate when the vehicle travels on a straight road without elevation change at a given speed in km/h.
P_{aux}	Energy consumed by the vehicle's auxiliary systems (e.g., air conditioning, lights) per second of travel.
L	Length of the segment in meters (computed by HERE).
Δh_{+}	Elevation difference between the end and the start of the segment in meters if positive, otherwise zero.
Δh_{-}	Elevation difference between the end and the start of the segment in meters if negative, otherwise zero.
t	Travel time along the segment in seconds (computed by HERE)

To bring all kinds of fuels to use the same units, a liter of fuel equivalent to kWh energy of electricity is considered. The P_{speed} curve is built using the WLTP tests[2] of vehicles. In addition, some tests will be conducted on real cars for validating the data values. The mobility service stores in its database the values of the parameters for typical means of transport. They are described in the following sections.

3.1.1. Electric Bike

An electric bike is a bicycle with an integrated model electric motor that may be activated to assist the user with pedaling. Because the engine has batteries that need to be charged, the generic energy model is used for electric bikes.

3.1.2. Electric Scooters

An electric scooter (or e-scooter) is a stand-up scooter powered by an electrical motor. Considered as a kind of micro-mobility, e-scooters are mainly designed with an oversized deck in the city center, on which the rider stands. The electric scooter needs to be charged. Hence, the generic energy consumption model is used also for this mode of transportation.

[2] https://carfueldata.vehicle-certification-agency.gov.uk/

3.1.3. *Generic Vehicle Classification*

Regardless of the fuels, ordinary vehicles are classified according to the Canadian's Fuel consumption guide[3]. Table 2 gives the classification. The use of Canadians classification aims to overcome the lack of European rules for classifying vehicles. This classification will be used to get the average vehicle's consumption per 100km/h according to its speed and the used fuel (P_{speed}). European vehicles are used instead of Canadian ones as defined in Table 3.

Table 2. Classification of vehicles in the Canadian energy consumption guide

Vehicle Class	Interior volume in liters	Vehicle Category	Gross vehicle weight rating in kg
Mini compact (I)	< 2 410	Small pick-up (PS)	< 2722
Subcompact (S)	2 410 to 2830	Standard pick-up (PL)	2722 to 3856
Compact (C)	2830 to 3115	Small sport utility vehicle (US)	< 2722
Mid-size (M)	3115 to 3400	Standard sport utility vehicle (UL)	2722 to 4536
Full-size (L)	< 3400	Minivan (V)	< 3856
Small station wagon (WS)	< 3680	Cargo van (VC)	< 3856
Mid-size station wagon (WM)	From 3680 to 4530	Passenger van (VP)	< 4536
		Special purpose vehicle (**SP**)	< 3,856

This classification is used to integrate the Euro Car Segment. The models are selected among the most popular sold vehicles [2]. For instance, Volkswagen Golf illustrates lower medium cars.

[3] https://www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/fuel-consumption-guide/21002

Table 3. Mapping of Canadian and European vehicle classifications

Euro Car Segment	Euro NCAP Class		Canadian Size Class
A-segment mini cars	Mini	Supermini	Minicompact (I)
B-segment small cars	Small		Subcompact (S)
C-segment medium cars	Lower Medium	Small family car	Compact (C)
D-segment large cars	Medium	Large family car	Mid-size(M)
E-segment executive cars	Upper medium	Executive	Large(L)
F-segment luxury cars	Luxury	Luxury	
S-segment sports coupés	Sport	Roadster sports	Two-seater(T)
M-segment multipurpose cars	Van	Small MPV	Minivan(V)
		Large MPV	
J-segment sport utility cars	SUV	Small off-road 4x4	Small SUV(US)
		Large off-road 4x4	Standard SUV(UL)

3.2. Generic CO2 Emission Model

The Kaya equation [3] is stating that the total emission level of CO2 can be expressed as the product of four factors: human population, GDP per capita, energy intensity (per unit of GDP), and carbon intensity (emissions per unit of energy consumed) [3] [4]. It is a concrete form of the more general $I = PAT$ equation [5] relating factors that determine the level of human impact on climate. Although, the terms in the Kaya equation allow to calculate emissions in terms of more readily available data, namely population, GDP per capita, energy per unit GDP, and emissions per unit energy. The Kaya equation concerns an entire population. Nevertheless, it was adapted by [6] [7] to evaluate the CO2 emission for individual entities in the system, e.g., vehicles. Equation for CO2 Emission of any vehicle is defined in Eq. 2:

$$E = C \times E_{eng} \quad (2)$$

Emission E along the road segment depends on the length, speed, and elevation difference. Parameters are described in Table 4.

Table 4. Parameters for CO2 emission equation

Model Parameter	Description
E_{eng}	Quantity of CO2 that is emitted per unit of consumed energy.

The mobility service stores in its database the values of the parameters for typical means of transport. They are described in the following sections.

3.2.1. Electric Vehicles

EVs are vehicles that are partially or fully powered on electric power, including electric bikes and scooters. EVs have low running costs thanks to the fewer moving parts for maintenance and they are very eco-friendly as they use little or no fossil fuels (petrol or diesel). CO2 emissions of EV (including Electric Scooters and bikes) are computed proportionally to the energy used and according to the country where the charging point is located. This data is available in several references according to the country, agency, and energy providers[4][5][6]. Table 5 gives the 2020 data of the European Environment Agency[5]. The values used in the simulator are updated according to the latest available data from the REDREAM ecosystem's database.

Table 5. CO2 emission per country

Country	CO2 Emission (gCO2/kWH)	Year of Measure
Croatia	133.8	2020
Italy	213.4	2020
Spain	156.4	2020
UK	230	2019

3.2.2. Fuel or Gas Engine Vehicle

Gasoline and diesel vehicles each use burning engines. A gasoline vehicle usually uses a spark-ignited burning engine, instead of the compression-ignited engines employed in diesel vehicles. In a spark-ignited engine, the fuel is injected into the combustion chamber and combined with air. The air/fuel mixture is kindled by a spark from the plug. Even though gasoline is the most common transportation fuel, other various fuel choices use similar parts and engine systems.

The resulting CO2 emissions depend on the used fuel. The generic energy model computes the spent energy in terms of KWH. Table 6 gives the CO2 emissions per unit of KWH of the used fuel[7][8] [2] [8]. Table 6 considers 100% efficiency. This efficiency will be adjusted according to the selected representative cars.

Table 6. Mapping from CO2 emission to kWH

Fuel Energy Source	CO2 Emission (gCO2/kWH)	Liters/kWH
Petrol	248.85	0.11320211
Diesel	259.34	0.09974024
Ethanol	215.9	0.14150264
Compressed Gas	236.85	0.15790172

3.2.3. Self-Charging Hybrid Engines

Self-charging hybrid cars mix a petrol or a diesel engine with electric power. To consider such a vehicle, the generic model of energy is derived from their fuel consumption since they can top the battery while on the move. So, the CO2 footprint of these vehicles is directly linked to the table above. The computed P_{speed} curve is derived from the fuel (liters per 100km) consumption.

3.2.4. Other Means of Transport

The mobility service supports other means of transport, such as public bus lines, trains, etc. These means will neither be implemented with specific energy consumption nor CO2 emission equations. From the user-centric point of view, the energy consumption of these means of transport is not directly supported by the prosumers. However, even if the prosumer is not consuming its energy alone, the means of transport get it

[4] https://www.rte-france.com/en/eco2mix/co2-emissions
[5] http://www.carbon-calculator.org.uk/
[6] https://www.sunearthtools.com/tools/CO2-emissions-calculator.php
[7] https://www.treehugger.com/fuel-energy-comparisons-85636
[8] https://www.omniapartners.com/fileadmin/public-sector/suppliers/T-Z/The_Grasshopper_Company/Marketing/flyers/The_Case_for_Diesel.pdf

from the public transport companies. There are many contradictory data that can be used to estimate the public transport CO2 emissions. They depend on several hypotheses about vehicles, engines, locations (urban, suburb and regional) and an average number of passengers. Hence, data are needed from a transportation company to feed the model: itinerary, kind of vehicle and number of passengers. However, such details are not available, at this stage of the project, for the already existing public transportation. To overcome this lack of information, the application gives an estimation of the CO2 emissions and the hypothesis used. The CO2 emission is an average value for the public transportation means. They are provided in Table 7. The values in this table are provided by the following public references.

Table 7. CO2 emissions for public transport

Means of Transport	Average CO2 Emission per Kilometre per passenger
Bus	160g (av. 10 passengers)
Rail	68g (35% full)

IV. Demo Sites

Within REDREAM, four demo sites are considered: Croatia, Italy, Spain, United Kingdom. Several expected features for the mobility service have been discovered and highlighted. Based on a software-engineering analysis, a generalization and shared definition of four mobility-related use cases that are implemented and deployed for the four REDREAM demo sites. These use-cases are generic types of usage of the REDREAM mobility services. These generic use-cases are shared between the four demo sites in which they are instanced. The first use-case computes the mobility key indicators from a trip request from point A to B with a specified mode of transport. The second use-case computes the key indicators for a trip between A and B and provides the best modes of transport in this case. The third use-case computes several trip solutions between A and B including different modes of transport. The fourth use-case provides tools for the gamification application that is implemented by the other REDREAM partners.

For modelling real-world scenarios, the traffic simulation needs infrastructure data for computing realistic traffic conditions. The quality of the input data is crucial. But collecting, processing, and validating such data is time-consuming. Sometimes it is difficult to receive real-world data. In particular, the real traffic light signal plans are rarely open to the public. Consequently, it is difficult for traffic researchers to analyze and evaluate their traffic algorithms under real-world conditions. Thus, realistic simulation scenarios must be prepared and described [9].

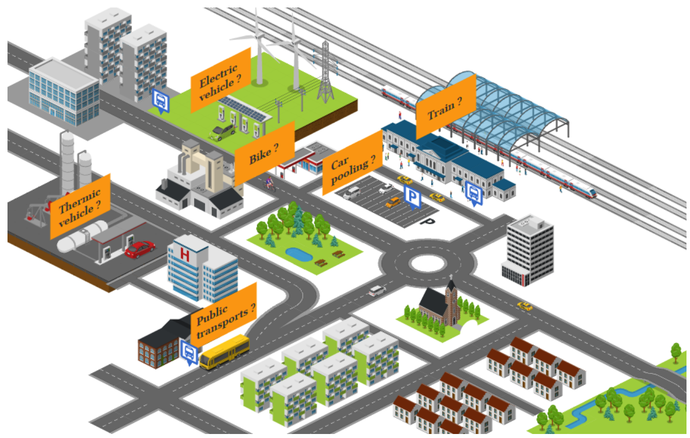

Figure 3. Demo sites

As illustrated in Figure 3, the end users would like to:

1) Evaluate their trips (daily or weekly trips) with standard indicators (distance, duration, etc.), energy consumption, and gas emission.
2) Be advanced in the best mobility choices (means of transport) for minimizing the impact on the environment.
3) Be advanced in the impact of mobility behavior and EV on home energy consumption.
4) Compare the user key indicators to the indicators of other users (according to gamification principles).
5) Support specific and multiple means of transport: EV, fossil-energy cars, bikes, scooters, public transport, car sharing, etc.

Experiments with 400 real prosumers will be conducted during 2023.

V. Comparison with Other Mapping Libraries

According to the description of the mobility service, one could say that several software libraries already exist on the Internet and may be used for responding to the above features, e.g., Google Map[9], Open Street Map[10] or HERE[11], to site few. One question arises: What are the key features of the REDREAM mobility service that make it different from the other mapping API such as Google Map, Open Street Map, etc.? Six major features are provided by the REDREAM mobility service that

[9] https://www.google.fr/maps
[10] https://www.openstreetmap.fr
[11] https://www.here.com

cannot be found all in the base features of the other mapping API:

1) *Global energy ecosystems:* Compared to other mapping API, such as Google, the mobility service is included in a general ecosystem that is not restricted to mobility. In this context, the mobility service is part of a larger system and the impact of mobility on energy consumption of a prosumer, and of this later his/her mobility is a key added value of the REDREAM ecosystem compared to most of the other mapping API. For example, the mobility service is included in a gamification application that enables the prosumers to evaluate their ecological impact, including the energy consumption at home and those related to mobility. Another example is related to the fact that the front-end application may recommend to the prosumer to use mean of transport in their daily travels depending on optimization criteria such as travel duration, energy consumption, greenhouse gas emission for example. The mobility service is also connected to other REDREAM services for obtaining the required information, e.g., the electricity price, for computing the mobility key indicators.
2) *Energy consumption from a user-centric point of view:* REDREAM mobility service computes the energy consumption of multiple types of modes of transport, including EV. For example, the other mapping API usually provides fossil-energy consumption but does not provide a relevant evaluation of the electric consumption. Additionally, most of the mapping API does not include the positions of the ECP.
3) *CO2 gas emission from a user-centric point of view:* REDREAM mobility service evaluates the emission of CO2 gas when fossil-energy vehicles are used, even for private or public transport. As one of the most challenging environmental issues, the effects of Greenhouse gas emissions (especially CO2 gas) are fundamental for the understanding of the impact of a project or a group of individuals on the environmental ecosystem [8]. We advocate that providing an estimation of the greenhouse gas (CO2) emission will enable the prosumer who is interested in her/his ecological impact to measure it, and therefore to increase her/his awareness. This indicator is commonly used by transport companies such as aerial companies for example. As for the energy consumption, most of the other mapping API do not provide an evaluation of the gas emissions, especially when EV are partly involved in the trips.
4) *Multiple solutions for a trip based on selection heuristics:* REDREAM mobility service can compute several mobility solutions, including different means of transport and possibly different time windows. These solutions will be computed depending on different heuristics. The other mapping API are also using selection heuristics, but they do not cover the full set of features of the REDREAM mobility service.
5) *Recommendations to the users:* In extension to the previous point, REDREAM mobility service can classify the different solutions to build a recommendation to the prosumers according to its mobility preferences. The mobility service is based on two layers of recommendation. The first layer, which is the most important, is the recommendation related to a specific mobility query from the prosumer. In other words, the mobility service can recommend a means of transport for a trip from points A to B according to selection criteria selected by the prosumer. For example, the mobility service may recommend the use of personal or shared EV for a specific trip. The second layer of recommendation is based on the storage of a history of the mobility trips for a prosumer. The mobility service will provide the necessary information to the front applications to show the mobility behavior of the prosumer for a larger time window (week, month) depending on the available data. Then, for example, the front application could highlight the best transport mode according to a criterion that is selected by the prosumer.
6) Better involvement of the users in new mobility services design: The key REDREAM's philosophy is to get the user more involved in the energy market. This also applies to the mobility market that significantly impacts energy consumption. The mobility supply is designed through a top-down methodological approach, where the behavior of the transportation demand is predicted, using various mathematical models, e.g., the classical four-step approach uses several models of mobility demand calibrated by statistical data [10]. The aim of the application is to bring the user into the loop of the design process of mobility services. The newly designed mobility services are suggested to users and evaluated by them according to their actual travel habits. The feedback of the users is used to improve the proposed service or to select the most popular one by stakeholders. The feedback is a score provided by the prosumers to indicate if they think that the novel mobility service is acceptable, suitable from their personal point of view. In other words, the prosumers will be able to vote for or against this novel service by providing a score feedback. This feedback management is not a feature of the mobility service, but

the service provides information to the front application for enabling the prosumers to give their feedback to this application.

These mapping APIs have many differences, as well as similarities. All of them are a part of the science of where but with different approaches. Several of them have an Open approach, e.g., Open Street Map, others have Closed approach depending on the collection and distribution of data, e.g., Google Map. All have many advantages and disadvantages over each other, but it completely depends on the user preference, which one suits them best. The choice depends upon the specific needs of the user and availability.
In the case of the REDREAM project, we opted to use the HERE mapping API that managed to provide the most complete set of features for mobility service. This choice is supported by several reasons: First, HERE is the only mapping API where the computation of the paths includes the ECP positions and the charging profile of the vehicle. Second, Electric Vehicles or EVs (including electric bikes) are fully supported by HERE, where the computation of the energy consumption for EV is provided for each path. Third, and even though HERE is not totally free, it provides 125000 requests/month for free, which is enough according to our evaluation of the expected needs. Indeed, the international implementation of the REDREAM mobility service will generate an average of 10 requests to HERE for each request of the REDREAM prosumer to the mobility service. It means that around 400 requests per day could be launched by these prosumers to the mobility service. We estimate that it covers the needs for the REDREAM demo sites.

VI. Conclusion

This paper describes the ongoing work related to the design, implementation and deployment of a mobility service that is providing user centric indicators to a group of prosumers who are interested on their impact on the global energy consumption and CO2 emission, and possibly to change their behaviors to find better energy consumption for their everyday life and minimize their CO2 emission.
The REDREAM mobility service is designed based on an agent-oriented paradigm for enabling the support on user-centric behaviors and indicators. The associated mapping library is HERE for supporting the road and infrastructure map. Mobility service differs from other mapping software, such as Google Map by supporting specific means of transports including electric vehicles, e-scooters, etc. and their possible usage in a single mobility behavior and using extra information such as ECP for computing the more accurate travel solutions as possible. The mobility service is designed as a service-oriented architecture to serve the rest of the REDREAM ecosystem.
The next steps of this on-going work include experiments in four demos sites (Croatia, Italy, Spain, UK) with almost 400 real prosumers. The feedback that will be provided by these users of the mobility service, through a set of gamification applications and web portals, will enable to adapt the parameters of the mobility service to adapt its computations to each user.

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