Abstract— Electric vehicles have pro-environmental advantages compared to traditional automobiles, or even hybrids: they can help reducing pollution and noise levels locally, and greenhouse gas emissions globally. However, there are still many challenges that the electric vehicles must overcome before reaching level of diffusion that can have significant impact on sustainability. This paper evaluates combined sustainability of electric vehicle and small-scale energy production. We propose a framework for sustainable electric vehicle – energy prosumer integration and outline a policy mix that is needed to support adoption of both renewable energy technologies and electric vehicles.

Index Terms—Renewable energy, electric vehicle, prosumer, sustainable, policy

I. INTRODUCTION

Climate change and growing need for energy are forcing policy makers to address how to accelerate adoption of environmentally sustainable products and services. Technology developments in renewable energy generation equipment, smart power grids and transportation solutions all enable new innovative ways for consumers to participate in sustainability transition taking place in various industries. Energy and transportation together contribute 49% of greenhouse gases emitted to the atmosphere [1]. With solar photovoltaic (PV) becoming affordable for households, more and more energy consumers are evolving into energy prosumers i.e. producers and consumers of energy. Electric vehicles (EV), either battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV) (see e.g. [2]), have been suggested as one solution leading to sustainable development of energy system as a whole through using renewable energy sources (RES) and vehicle to grid (V2G) integration. However, socio-technical barriers such as perceived uncertainty in addition to performance issues related to battery range and cost [3], charging interoperability, taxation policies [4], and lack of awareness of governmental incentive programs [5] are slowing down consumer adoption of EVs. Local renewable energy sources (RES) and EVs together could be a way towards minimizing emissions and using the electricity system in an efficient way. Hence, in order to steer the development into the right path, governmental interventions are seen as vital to ensure wide scale adoption of green innovations (e.g. [6]).

The paper has been structured as follows: Firstly, we review theoretical framework for the socio-technical transitions taking place at transportation and energy sectors and assess policies and incentives that are available for sustainable innovations. Secondly, we introduce the research approach followed by introduction of a framework for sustainable EV-Prosumer interactions and mapping of policies that support the framework. Lastly, discussion section summarizes the policy implications and proposes agenda items for future research.

II. THEORETICAL REVIEW

A. Socio-technical multilevel perspective – energy and transportation sector transitions

Systemic changes, like shift to EVs, do not happen easily. They require profound changes in products, services and technologies around the new innovation. Transition Management (TM) and Multi-level perspective (MLP) are common frameworks for analyzing such industry transitions [7]. TM refers to an approach to steer long-term changes that take place in socio-technical systems. Industry transitions should be governed bottom-up with experimental approaches and explicitly designing processes for learning-by-doing.

MLP considers transitions at different interlinked levels of socio-technical systems. Central dynamics take place between niche players in micro level and present regimes on meso level. Niches, the bottom layer, are legally or otherwise protected spaces where new radical innovations and technologies can develop. Landscape, the top layer, is global in its nature and refers to social values, institutions and beliefs of society broadly. For a meso-level regime transition to happen there has to be pressure from both, the upper landscape and the lower niche levels. There is no uniform definition for socio-technical regimes and in some cases, regimes can be used as synonyms to markets or sectors [8]. Regimes are also multi-dimensional including dimensions like user practices, policy issues, knowledge and infrastructure.

The socio-technical framework is useful for energy sector as it can be used to analyze dynamics between new and incumbent players and their objectives. For example, Geels [9] investigated...
how regime mechanisms can stabilize the development of niches. Furthermore, legacies, like earlier investments in large production sites and grids, create path dependencies and lock-ins. These aspects are important in the MLP framework because they create stabilizing forces that keep the regime level in power [10], [11].

B. Diffusion of innovations

Diffusion of innovation is a process describing spread of innovations over time [12]; different adopter groups take new innovation into use on progressive order. The first adopters are the innovators, who are most often technology enthusiasts that can tolerate products with complexity and are not very sensitive to costs. The next adopter group is the early adopters that could be interested in the new technology solution due to a special need or to impress their peers. The early adopters often wish to be opinion leaders and like to recommend products. They also may have strong pro-environmental reasons to adopt new technologies early. Once the early market adoption takes off properly, late market adopters, including early majority, late majority and the laggards, can be reached. The late market, or mass market, adopters usually expect ease of use, good value for money and clear benefits.

Prosumer adoption of RES varies largely by market. Solar PV price levels have dropped globally and the energy production is becoming more affordable for small scale producers. Some governments have launched attractive economic incentives to further boost solar PV adoption and this has caused fast diffusion in Germany, for example. Nevertheless, prosumer adoption of RES is in the early market phase in most markets. EVs particularly are currently in the early market phase; the global average market share being mere 0.2% of the total passenger light duty vehicle circulation stock worldwide [13]. Some of the countries are further ahead; Norway is the leading market for EV adoption with sales market share of 29% (combined BEV and PHEV in 2016) followed by the Netherlands (6.4 %). China, France and United Kingdom have sales market share of 1.5%. China and the United states are clear leaders in the EV volumes. In 2016 there were 750 thousand new EV registrations and the total vehicle stock was ca. 2 million [13].

C. Policies to support diffusion of sustainable technologies

Policy support is commonly seen as critical accelerator of environmentally sustainable innovations. Environmental policy instruments (EPI) have been a center of interest in European countries where innovative policies have been introduced to complement traditional regulation to achieve environmental goals. Basic public policy instruments can be divided to regulatory instruments, financial instruments and information transfer (e.g. [14]). There are several ways to categorize EPIs in more detail. For example, OECD [15] has used: command and control, economic instruments, liability and damage compensation, education and information, voluntary approaches (VA) and management and planning. A simpler way to describe different types of EPIs is to refer to them as “market based” or “command and control” (or “regulatory”). Additionally, level of coerciveness, or intrusiveness, is often used to categorize EPIs (e.g. [16]).

Policy cycle phase affects to the policy instrument choice. The key policy phases are: 1) agenda-setting, 2) policy formulation, 3) policy decision-making, 4) policy implementation, and 5) policy evaluation [17]. As EVs are in the early phase and governments are still evaluating possible EPI options, many of the instruments have been designed to boost the EV adoption [4] by economic means. Once the adoption reaches desired level and EVs are able to be self-sufficient, most of the economic instruments will be phased out. Development of micro-generation policies in energy markets are ahead of EVs and energy policies have stabilized to some extent, albeit they are in a flux as the results of the interventions are observed and corrective moves made [18]. EV policies should continue to concentrate on early adoption and early markets rather than mass markets [19] as this has more impact on the increasing adoption of the EVs. Recent studies also show that EV policies do indeed influence propensity to purchase EVs in addition to socio-psychological determinants [20].

III. RESEARCH APPROACH

EV sustainability largely depends on whether emission free energy sources are used to power up the vehicles. We are interested in exploring how microgeneration (based on RES), by small scale energy prosumers, and EVs (in particular BEVs) together can increase sustainability of the energy system (Research Question (RQ) 1) and what kind of policy mix would be required to support the combined EV – Prosumer activity (RQ2). Our approach is to assess EV and Prosumer related technologies, sustainability factors, adoption challenges and policies. As a conclusion, we propose a sustainable EV – Prosumer (SEP) framework and outline a policy mix to support it.

The SEP framework must fulfil two core requirements. Firstly, the framework must be based on combined sustainability impacts of both EVs and small-scale energy production by prosumers (i.e. prosumption). Hence, we present short analysis of EV and prosumption benefits and challenges and highlight the sustainability aspects of both. Secondly, both EV and prosumer market share must rise to a level required to have impact on the overall sustainability of energy and transportation systems. Policy support is critical in accelerating the adoption of new environmentally sustainable technologies. We will thus assess both EV policy options and prosumer support options that together are necessary to sustainability of the SEP framework.

A. EV sustainability benefits and challenges

Sustainability of EVs has been under constant debate. It is widely accepted that the main EV sustainability benefits are reduction of local emissions and noise levels as well as overall reduction of CO₂ emissions in case the electricity used to charge the EV batteries is generated based on RES.

EV’s are facing multiple challenges in terms of consumer acceptance. BEV availability in car manufacturer portfolios has been limited; consumers do not find the type of vehicle they would like to buy and thus opt for a vehicle with an internal combustion engine (ICE). Price gap between EV initial purchase price and a comparable ICE vehicle is still considerable. Even though maintenance and use is less
expensive, the initial capital expenditure is preventing many consumers from making the decision to buy an EV. Battery price levels are dropping as the volumes grow, but the battery price is still the main cost differentiator for EVs. There are also usability issues; current EV driving range (up to 300-400 km) is seen as limiting, charging times for EVs are perceived as too long and charging infrastructure (especially smart chargers and fast chargers) is in its infancy. Developing better solutions for charging is important as consumers feel uncomfortable about acquiring a vehicle that they may not be able to charge when needed, outside their home.

B. DER/microgeneration benefits and challenges

Emission free energy generation using RES is the most obvious sustainability benefit of prosumption. Energy produced is free of charge (unless charges are posed through regulation) and excess energy can be stored in external batteries (e.g. EV batteries). Demand response (DR) schemes are developed to better integrate energy users to the energy system through balancing consumption from peak to non-peak hours. Distributed energy resources (DER) bring much needed flexibility to the energy production and if spread widely, can have an impact on the global emission reduction.

On the other hand, energy regime incumbent actors have many concerns over increased DER/microgeneration. Variable energy generation can be difficult to predict and does not fit in optimal way to the current energy market processes. There are concerns that small-scale distributed energy resources (DER) can challenge the power grid stability. If not planned, built and managed professionally, energy communities and micro-grids could cause severe problems to the electricity system. Even an “off grid phenomenon” can take place in case enough prosumers decide to rely on self-generation. This could happen in case the prosumers are able to generate enough energy to be self-sufficient or the national energy price levels become too high.

C. EV, DER and DR policies

Economic instruments have been found to be essential to boost adoption of new technologies, albeit other incentives are also important. However, there is consensus among experts and policy makers that once the diffusion reaches mass markets, economic instruments should be phased out. Table 1 maps policies to EVs, microgeneration and demand response (DR).

The categories (in Table 1) vary from regulatory through market based approaches to voluntary approaches. The policies are relevant from socio-technical MLP: most of the command and control policies are driven from landscape (macro) level (e.g. EU directives) to influence the system while innovative voluntary approaches and self-regulations can emerge bottom up from micro (niche) level.

There are multiple macro level policy instruments that are dominating the DR and microgeneration possibilities and attractiveness [21]–[23]. EV policies on the other hand are more market based than DER/microgeneration policies and, if they exist at all, are currently designed to boost EV adoption. Many governments are still very much in the agenda-setting phase related to EV policies.

<table>
<thead>
<tr>
<th>TABLE I. SUMMARY OF EV AND DER RELATED POLICIES</th>
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<td><strong>EPI policy type</strong></td>
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<tr>
<td>Regulatory</td>
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<td>Economic</td>
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<td>Management and planning</td>
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<td>Information, education and other</td>
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<td>Voluntary agreements</td>
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IV. SUSTAINABLE EV-PROSUMER (SEP) FRAMEWORK AND POLICY MIX

As described above, EV sustainability is noticeably enhanced when renewable energy sources are used to charge the EV battery and EV is connected to power grid and can be used for demand response, through vehicle to grid (V2G) connection, and to balance peak-off peak consumption. Furthermore, sustainability benefits from the DER and prosumption are based on energy generation using emission free renewable energy sources, increased energy efficiency and participation in demand response schemes, that can further be enhanced by introducing energy storage (battery or EV) and smart metering.

The SEP framework presented in Figure 1 describes energy prosumer centric microgeneration based on solar PV and using batteries and EVs as energy storage. The framework includes grid connection for both EV and solar PV / battery storage.

Figure 1. Sustainable EV – Prosumer (SEP) Framework

Figure 2 summarizes policy mix support requirements for SEP framework. Policy instruments cover EV policy instruments and DER/microgeneration policy instruments. In short, the policy instruments to push SEP as the preferred way to produce, store and use energy must be supporting a) adoption of EVs, batteries, smart meters and solar PV, b) enable grid and V2G connections and c) incentivize participation in DR schemes.

Self-generation of energy must be promoted and incentivized and prosumers need to be encouraged to connect their batteries and EVs to the power grid and participate in demand response schemes. Policy mix for SEP should include at least support for technology adoption of at least solar PV, EVs, and smart meters. This can be achieved through market based policy instruments that incentivize purchase decision of EVs or solar PV. In addition, regulative instruments including changes in legislation are needed to ensure availability of smart metering in residential buildings and enable small scale producer’s grid connection. Continuous R&D investments are still required for charging technology and infrastructure development and battery technology development. Information campaigns and education can help reducing EV related concerns and misconceptions.

Figure 2. SEP policy mix

EVs require similar kind of dedicated grid connection requirements, which have enabled solar PV diffusion. A non-discriminatory access to electricity network is needed and standards and communication protocols for charging stations have to be defined. Charging station deployment targets and building codes with minimum charging station mandates ensure that enough EV parking spaces are built. Property laws should be changed so that especially housing companies can easier deploy charging stations. Many countries have also introduced financial incentives for them, which further accelerates their diffusion [13].

Prosumer-level DR requires regulation that opens the electricity market for new end-user business models. Smart meter rollout is the first step. The market needs to be opened to new independent actors like aggregators. For further deployment, aggregation requires standardised products, customer’s better access to data, small enough bids to get into the electricity market and protection of consumer privacy [23],[24]. Introduction of advanced pricing schemes, like Time-of-Use pricing or real-time pricing would incentivise consumers to change their consumption patterns. Network tariff structures are being re-designed away from volumetric rates to enable bi-directional electricity flows. Yet, tariff design has to be done carefully so that DR and self-consumption are not overly discouraged by fixed tariff rates. Also, DSOs’ remuneration models should incentivise acquiring flexibility services [25]. Consumers should be well informed of their contract options and the system benefits they can bring.

V. DISCUSSION

SEP framework is based on combined sustainability benefits of EVs and DER/Microgeneration. The framework positions the prosumer, i.e. a small energy customer-producer, in the focal point and proposes that by accelerating the adoption of microgeneration technologies (such as solar PV), Smart Meters, EVs and V2G and at the same time taking a systemic approach to policy mix design, the combined sustainability impacts of the system can be extended.

When comparing EV and DER/microgeneration policies, it is evitable that EV policies are less regulative than the DER/microgeneration policies. EV push is based heavily on taxation and market based economic instruments as well as on
information and education. DER/microgeneration on the other hand has a lot of command and control type of regulations that are related to emission restrictions of energy generation, trading and ensuring security of energy supply and keeping the power grid stable.

The SEP framework provides an integrated view on the succession of different policy instruments and their effects in general level. As such, it provides multiple avenues for future research. For example, how impact of policies can be measured in an integrated way, what are the multi-policy selection spaces that are feasible and how they are forming in difference phases of evolution. Also, based on the SEP framework it is possible to conceptualize various sustainability paths based on alternating multi-policy instruments targeting multiple impacts.

Novelty value of the paper lies not so much on the SEP framework alone, but rather on the mapping of a possible policy mix that can support the combination of sustainable energy production by small scale producers and EVs. There is earlier and ongoing research on EVs, V2G, DER and DR, however, the research lags behind in integrated policy mixes that are needed to ensure that the benefits of technology development are fully exploited and to maximize consumer value proposition for sustainable technology adoption. Policy makers should focus on more systemic approach when designing policy instruments and find policy synergies to better support sustainability transition that is taking place concurrently in multiple sectors.

REFERENCES

