

Electrifying emerging markets: the case of Costa Rica

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Executive Summary

Electrification of transportation by using local, renewable energy sources is key to avoiding adverse health, environment and energy impacts of increasing transportation work in emerging economies. For Costa Rica, whose electricity supply is already almost completely renewable, electric vehicles (EVs) will also play a key role in meeting the country's climate commitments. This paper presents an EV deployment scenario in the order of magnitude required to meet climate commitments and analyses the potential impacts on the electricity system. Using normalized grid planning data obtained through international pilot projects, we find that unmanaged EV charging could increase system peak electricity demand by 32% in 2030. Finally, we discuss possible residential smart charging strategies to mitigate peak demand growth on the grid.

Key words: consumers, deployment, light vehicles, market development, smart charging

1 The case for electric mobility in emerging economies

The relationship between transport and economic development goes two ways. On the one hand, increasing transport drives economic development, by improving economic efficiency, driving investment and innovation, helping markets for labor, products and services function better, and creating new recreational and social opportunities for people. On the other hand, economic development can also increase demand for transport, as people increase their standard of living. The relationship is particularly strong in the emerging phase of an economy's development, but tapers off as the economy matures [1,2].

On the other hand, transportation is also a major cause of health problems, environmental damage and climate risks. Vehicles fueled by fossil fuels emit a range of pollutants, including nitrogen oxides (NO_x), particulate matter (PM) and carbon dioxide [3]. As a result, 92% of the world's population lives in places where the World Health Organization's air quality guideline levels are not met. The organization estimates that outdoor emissions cause more than 3 million pre-mature deaths per year [4], while in the USA, NO_x and PM emissions from *road transport* cause an estimated 58,000 premature deaths per year [5].

The dilemma presents itself: how can countries and cities grow their transport systems while at the same time creating attractive, healthy and climate-resilient livelihoods for their citizens?

Lately, electrification of transport is proving to be a promising solution. The number of electric vehicles (EVs) world-wide passed two million in May 2017, and the next million is expected to be delivered by early 2018. China deployed more than 350,000 EVs in 2016, and in Norway, EVs are already capturing 35% of the market for new vehicles.

It also seems as though Dieselgate has finally woken up incumbent automakers, policy makers and consumers to the fallacy of "clean" fossil fuels. Dieselgate showed that most vehicles, whether due to questionable "test optimization" or unlawful cheating, have much worse emissions in real-life than in the laboratory [6–8]. Clearly, making internal combustion engines clean where it really counts - on the street -

would require both expensive vehicle technologies and expensive monitoring of real-world performance.

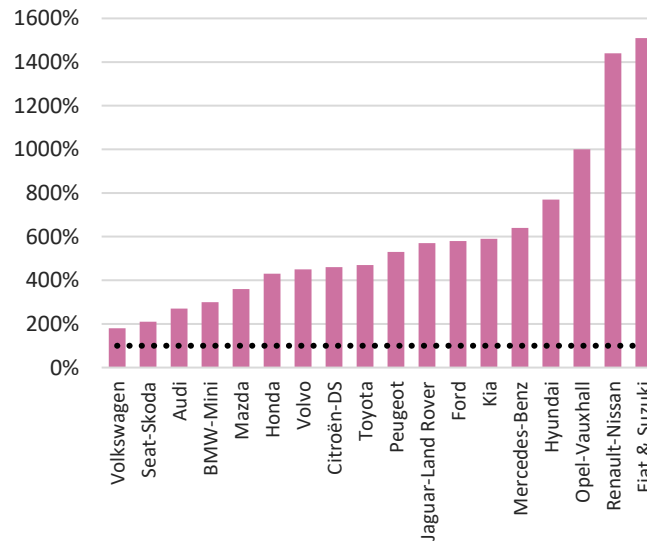


Figure 1: Diesel vehicles' actual NOx-emissions compared to legal limits. Source: [6]

What is the prospect for electric mobility in emerging economies?

Is the recent success achieved in developed nations like Norway or industrial powerhouses like China transferable to emerging economies? Could a country like Costa Rica, a small Central-American nation of 4.6 million people and a GDP of around 15,500 USD per capita, be a champion of electric mobility?

1.1 Costa Rica

Costa Rica aims to accomplish a "sustainable and low greenhouse gas emitting energy system" in terms of electricity generation and transportation [9]. In the Paris Climate Agreement, Costa Rica committed to reducing its greenhouse gas (GHG) emissions by 25% from 12.4 million tons in 2012 to 9.4 million tons in 2030 [10]. Since its electricity generation is already almost completely renewable [11], Costa Rica cannot, like most countries, achieve significant emission reductions in electricity generation. Instead, it must focus on transportation and particularly road vehicles, which made up 44% of total greenhouse gas emissions in 2012 [12], see Figure 2.

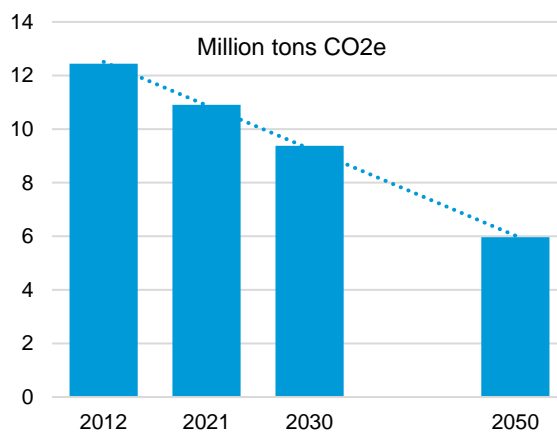


Figure 2: Costa Rica's GHG emission commitments [10].

With its economy still emerging, Costa Rica's vehicle fleet more than doubled from 2000 to 2014, led by strong growth in cars and motorcycles, see Figure 3 [13]. However, since car ownership per capita is still just half the level in industrialized nations, the trend will likely continue over the next decades.

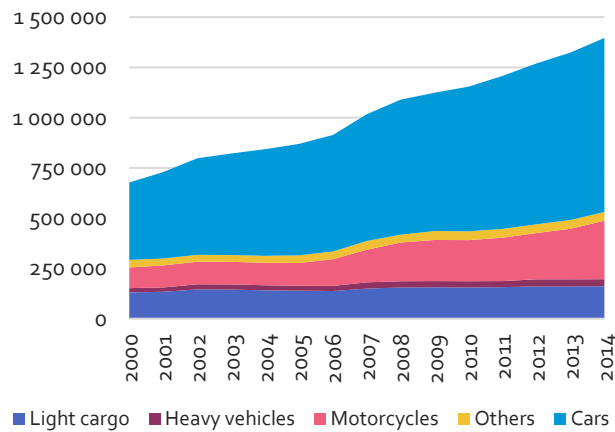


Figure 3: Costa Rica's vehicle fleet. Source: [13]

Meanwhile, air pollution in Costa Rica's greater metropolitan area is already well above WHO limits, and the worst air quality is found just outside the largest children's hospital [14].



Figure 4: A bus driving in central San José. Image credit: [15]

Costa Rica's electricity system is already almost completely renewable and emission-free. In 2015, renewables made up 99% of electricity generation, and average emissions from its electricity generation was 31 kg CO₂ per kWh in 2015. Large renewable energy resources remain untapped [11,16], providing more than enough renewable energy potential to meet new demand for electricity for vehicles. Clean, renewable electricity means that EVs in Costa Rica not only eliminate tail-pipe emissions, the ones that contaminate urban air quality and make people sick – they also eliminate indirect emissions occurring throughout the energy supply-chain, see Figure 5.

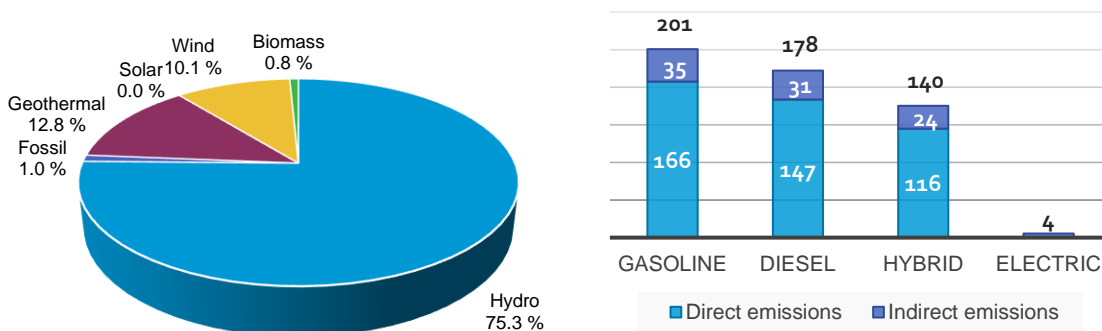


Figure 5: Electricity generation share by source in 2015 (left) [11], and energy-related CO₂ emissions for a compact SUV (gCO₂/km). Source: own elaboration based on [7,11,16,17].

Electric mobility would also create significant micro- and macro-economic benefits for Costa Rica, since electric vehicles are three times more energy efficient than traditional cars and can use local, renewable electricity instead of imported fossil fuels [18]. In 2012-2016, Costa Rica spent an average of 3.5% of GDP importing fossil fuels, most of which were used for road vehicles [19].

Zero-emission travel is also a natural next step for growing and strengthening Costa Rica's tourism industry, which has emerged as a top engine for economic growth, representing 5.3% of GDP [20]. When tourists are going electric at home, they will be expecting to do so during their eco-travel in Costa Rica as well. Signs of EVs as promoters of eco-tourism are emerging internationally [21].



Figure 6: LEFT: Electric tour coach in France. This size and type of coach is widely used in Costa Rica's tourism industry. Photo credit: B.E. green. RIGHT: Costa Rica's global positioning is centered on environmental stewardship and green credentials. Photo credit: Costa Rica tourism board.

2 Costa Rican EV deployment scenario

Given the multiple benefits and opportunities that electric mobility offers Costa Rica, how quickly could Costa Rica deploy electric vehicles? Is it conceivable that Costa Rica in the next 10-15 years could follow a similar path as Norway? The answer depends on factors like:

- What is the cost of ownership, including fuel savings and maintenance costs?
- Can EVs compete on price and can consumers afford them?
- Do consumers prefer EVs?
- How practical are EVs, considering ease of charging, geography and mobility patterns?
- Are sufficient policy support mechanisms in place? How important are EVs to meeting national energy and climate targets?
- Will consumers have sufficient EV offerings to choose from?

These factors are discussed below, comparing with those of Norway where relevant.

2.1.1 Cost of ownership

EVs are already cheaper to own and operate than traditional vehicles in Costa Rica. With gasoline at \$1.07 per liter and residential electricity at \$0.15 per kWh [22] and an assumed consumption of 8 liters and 15 kWh per 100 km for gasoline and electric vehicles respectively, driving an EV costs 1/4th of a gasoline vehicle. Nocturnal charging with time of use (ToU) rates increases fuel savings to 91%, see Figure 7. With 15,000 km per year, annual fuel savings are \$950 and \$1,150 for flat and ToU rates respectively.

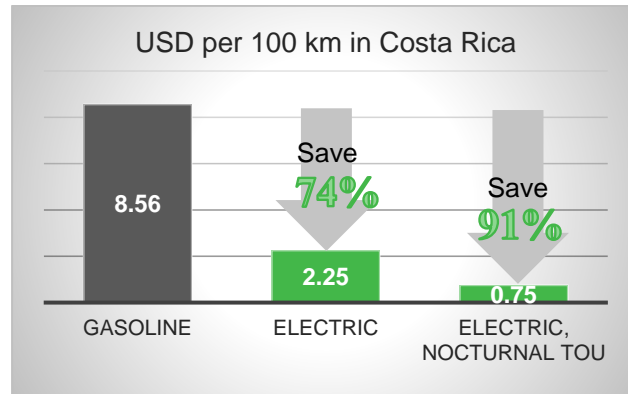


Figure 7: Cost of driving 100 km with gasoline and electric compact SUVs. Source: own elaboration based on [22].

In addition to fuel savings, Costa Rican EV drivers would accrue even larger maintenance savings compared to their Norwegian peers. For example, Costa Rica’s lower fuel quality means vehicles need replacement of motor oil and oil filters twice as often as in Norway, typically every 7,500 km.

2.1.2 Acquisition cost

In Costa Rica, EVs are already taxed lower than conventional cars (0% instead of 30% in fuel consumption tax, applied at the time of purchase; 10% is charged on hybrid and plug-in hybrid vehicles). However, since the average price of new cars is around \$22,000 [23], EVs are still considered too expensive for the masses. For example, the Hyundai Ioniq EV (see Figure 8), which has yet to be launched on the Costa Rican market, would according to insiders be expected to cost around \$37,500 at launch with the prevailing tax regime, whereas the conventional hybrid version of the same car, which already is available on the local market, costs \$29,000.



Figure 8: Hyundai Ioniq EV. Photo credit: Hyundai.

Since the Ioniq EV represents a popular vehicle class in the Costa Rican market, it can serve to illustrate how different factors can be expected to bring the price down in the near term:

- **Legislation:** Proposed legislation would expand purchase tax exemptions to include the 13% sales tax and 1% import tax, bringing the purchase tax rate for EVs to zero. In the case of the Ioniq Electric, this would bring the price down to about \$33,000, see Figure 9.
- **Market:** As the market scales up and competition grows, an additional 12-15% price drop can be expected. The Ioniq EV would likely drop well below \$30,000. For reference, the current, tax-exempt price in Norway is \$26,900, and the suggested retail price at launch in the UK was \$28,800 + VAT [24].

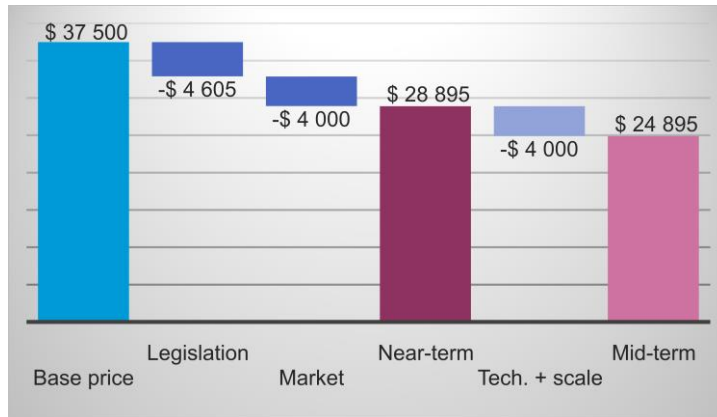


Figure 9: Expected near-term price reductions due to proposed legislation and expected market dynamics, and mid-term price reductions due to technology improvements and economies of scale. Source: B.Utgård/ESCOIA analysis.

Additional price reductions are expected in the future, as falling battery costs [25,26] and manufacturing economies of scale make automakers and analysts forecast that EVs will cost about the same as fossil-fuel vehicles with equivalent performance within the next 5 years [27,28]. For example Volkswagen has stated that the I.D. electric vehicle (see Figure 10) will cost the same as a similarly powered diesel car at launch in 2020 [27]. A reduction from \$250 to \$100 per kWh of battery capacity, which is predicted to happen by the early 20's [29], would alone reduce the manufacturing cost of the Hyundai Ioniq EV by \$4,200. Adding cost reductions of this order to the equation, the price would drop below \$25,000, see Figure 9.



Figure 10: Volkswagen's I.D. electric vehicle will launch in 2020 at a price like a similarly powered diesel car. Image credit: Volkswagen.

2.1.3 Consumer preference

If the total cost of ownership (TCO), the combination of acquisition and ownership costs is attractive and improving, a key question remains: Will consumers prefer EVs over traditional alternatives?

Recent experience from Norway, where the TCO due to financial incentives is already significantly lower than traditional vehicles, suggests that they will. For example, in 2016, the battery-electric (BEV) and plug-in hybrid electric (PHEV) versions of the VW Golf (e-Golf and GTE respectively) outsold the gasoline and diesel versions by 2:1, see Figure 11 [30]. With increased range, the 2017 e-Golf will likely grow further in popularity.

Evidence also shows that when consumers have gone electric, they stay electric. 88% of 3,000 BEV owners surveyed in Norway said they would definitely buy a battery-electric vehicle again, while less than 1% said they would not [31].

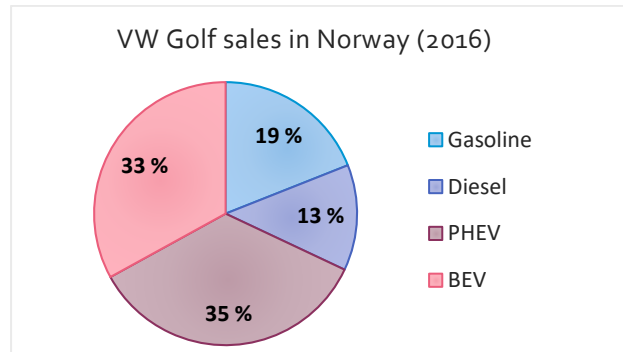


Figure 11: Consumer preferences for different versions of the VW Golf in Norway in 2016 (BEV = e-Golf, PHEV = Golf GTE). Source: [30]

A citizen consultation carried out by Costa Rica Limpia, a citizen group, in 2016 showed that 7 out of 8 of participants would prefer an EV if given the choice [32]. As Costa Rica's first citizen festival on electric mobility took place in April 2017, pressure was growing on congress to pass legislation to improve incentives for electric vehicles. By June 2017, all major parties in congress had vowed to vote for the proposed bill.



Figure 12: Costa Rica's first electric mobility festival was hosted by Costa Rica Limpia in April 2017. Image credit: Costa Rica Limpia / Sofía E. Corrales. www.movilidadelctrica.org

2.1.4 Practicality and adequacy of EVs in Costa Rica

93% of Costa Ricans live in detached homes, where home charging is as easy as connecting the EV to a normal electricity plug. In Norway, the corresponding figure is 62%, while the figures for the 28 EU member states and Spain are just 34% and 13% respectively (see Figure 13). While most Europeans need access to public charging infrastructure to get an EV, Costa Ricans can predominantly rely on home charging.

Moreover, since Costa Rica's population density is more than 6 times higher than Norway's, EVs would need far less investment in public charging infrastructure than Norway. This can be illustrated by considering the density of petroleum filling stations: Norway has 80% more stations per vehicle than Costa Rica. This is in part due to Costa Rica's population density being 6.8 times higher than Norway's.

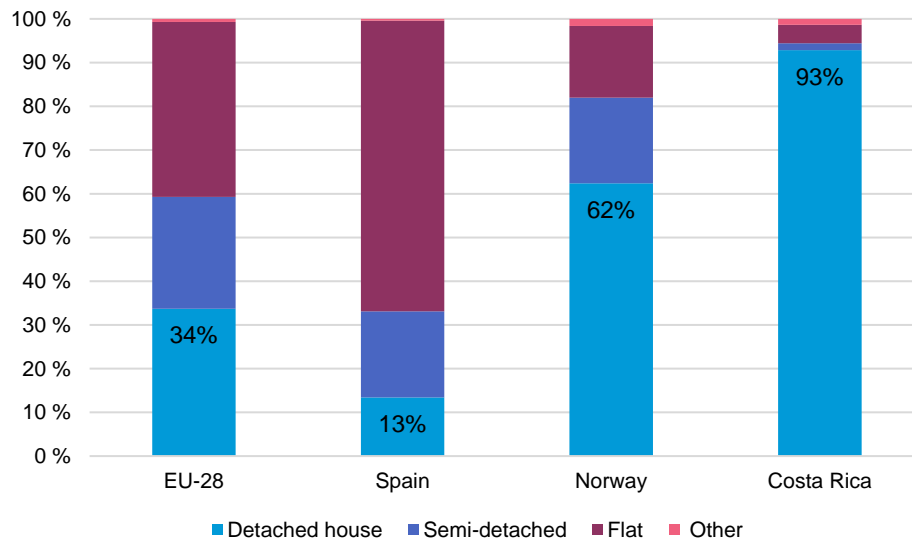


Figure 13: Residential patterns in the EU and Costa Rica. Source: [33,34]

In terms of topography and climate, Costa Rica's conditions are better suited than those of Norway. Both countries are rather hilly, which in Norway has proven not to be an issue for modern EVs. However, Norway's relatively low average temperature of 4.3C negatively impacts the efficiency and range of EVs, which can be reduced by as much as 25% in winter compared to summer [31]. By comparison Costa Rica's average temperature, 24.7C, is right in the optimal operating temperature range for EVs [35].

2.1.5 Policy environment

Costa Rica's ambitious climate commitments (see Figure 2), its positioning as a leader in environmental stewardship and its nearly 100% renewable electricity system suggest the country is well poised to enact policies promoting electric mobility.

Some incentives for EVs are already in place. BEVs are exempt of 30% fuel consumption tax and void of the one-day-per-week circulation restriction that traditional vehicles are subject to. Meanwhile, both state-owned electric utilities and private players have begun investing in and offering EV charging.

However, with less than 300 EVs on the road to date, stronger market signals and incentives are required invigorate and expand the market. The proposed policy bill due for vote in Congress in the second half of 2017 would largely meet this requirement.

2.1.6 EV offerings and supply

Even if the TCO is attractive, consumers must be able to find a car that suits both their needs and taste. Experience from Norway shows that as the number of models on offer grows, so does market share, see Figure 14.

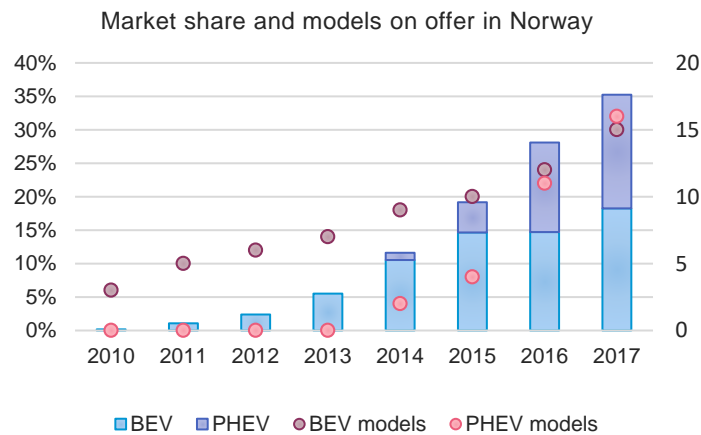


Figure 14: EV market share and number of models on offer in Norway. Source: [36].

While market shares of 18% and 17% for BEVs and PHEVs respectively in the first quarter of 2017 is already impressive, they will likely continue to grow in the coming years. First, the highly-anticipated Tesla Model 3 and Opel Ampera-E (a rebranded Chevrolet Bolt), which offer ranges of around 500 km on one charge and cost around \$35,000, are expected on the market later in 2017. Moreover, zero BEVs and only three PHEVs are yet on offer in the highly popular compact SUV class. This will likely change soon, as already announced, affordable electric SUVs come to market in the next couple of years.

Responding to growing market demand, Costa Rican automobile distributors have recently introduced the first plug-in EVs on the market, including the BMW i3 and the Mitsubishi Outlander PHEV [37]. However, other distributors have been reluctant to launch EVs on the Costa Rican market, suggesting policy interventions could be needed to shift the market into self-driven growth.

Impatient with local distributors, pioneering consumers have started importing used EVs. A recent experience shows that buying a one year old Nissan Leaf in the USA, bringing it to Costa Rica, paying taxes and legally registering costs about \$20,000. The rather attractive economics suggest used EV imports will likely grow in coming years.

2.2 Scenario for private and light- commercial Electric vehicles

The scenario developed below focuses on cars and light commercial vehicles (less than 3,500 kg), which make up 63% and 17% of Costa Rica's 1.5 million vehicles respectively [20], see Figure 3, and make up two thirds of transport sector greenhouse gas emissions [12]. Annual imports of new vehicles is 10,000 light duty commercial, and 47,600 and 22,000 new and used private vehicles respectively [38].

Figure 15 presents a scenario for deployment of private and light commercial EVs in Costa Rica. The scenario extrapolates 2016 vehicle sales until 2030, and assumes EV market shares based on a holistic assessment of drivers and barriers as discussed above and summarized in Table 1. Green shades indicate conditions deemed favorable for EVs.

Factor	Norway	Costa Rica
Fuel savings (15,000 km/y)	\$1,750	\$950- \$1,150
Oil change interval (km)	15,000	7,500
GDP/pop	\$62,084	\$15,595
Avg. new car price incl. tax	\$45,000	\$22,000
Environmental awareness	High	High
Climate commitments	Ambitious	Ambitious

Renewable electricity	98%	99%
Inhabitants/km	14	95
Homes with private parking	62%	93%
Number of filling stations	1,580	346
Distances: North-South x East-West	2,500 km x 600 km	500 km x 400 km
Topography	Hilly	Hilly
Average temp.	4.3C	24.7C

Table 1: Comparison of factors influencing the possible rate of electrification of the Costa Rican vehicle fleet. Source: own analysis.

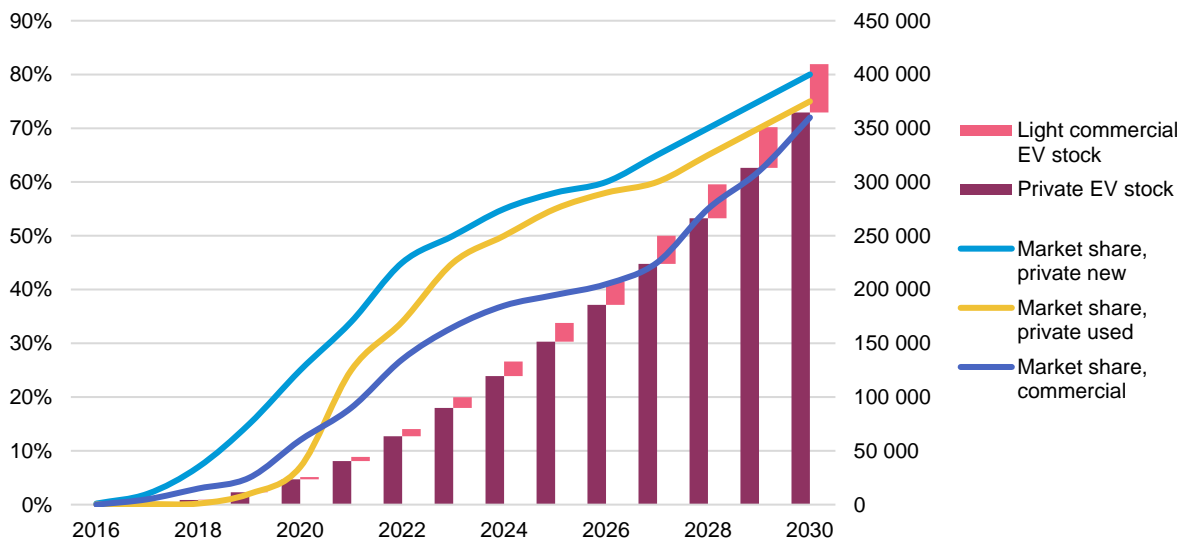


Figure 15: EV deployment scenario for Costa Rica. Source: own analysis.

2.2.1 Outcomes

Assuming an average of 15,000 electric km per vehicle per year and an average CO₂ emission factor of 150 g/km for the vehicles replaced, emission reductions amount to 921,757 tons per year. That equates to 19% of the country’s transportation emissions in 2012 and 31% of the reductions required for Costa Rica to meet its climate commitments by 2030.

If average avoided fuel consumption is 6.5 liters per 100 km, gasoline and diesel imports would be reduced by 2.5 million barrels of refined oil products per year, around \$175 million at current prices, not including delivery and logistics costs [19].

The ~410,000 plug-in electric vehicles circulating on Costa Rica’s roads by 2030 would, assuming on average 15,000 all-electric km per vehicle per year and 0.16 kWh energy per km driven, consume 1.0 terawatt-hours (TWh) of electricity per year. This represents a 9.3% increase in energy demand compared to 2015, see Figure 16.

While this is a substantial increase, it is in the same ballpark as the forecasted growth in distributed generation (DG) with rooftop solar panels within a similar time frame [39]. Distributed generation reduces the amount of electricity bought from the grid and thereby electric utility companies’ revenues. A growing number of electric vehicles would more than offset this revenue loss. Smart charging could also be implemented to help manage increasing supply and demand variations due to solar DG.

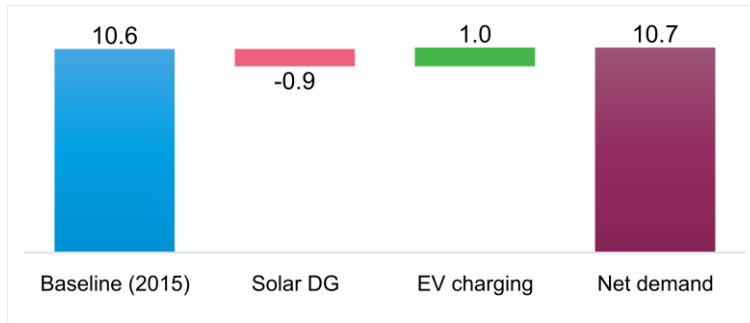


Figure 16: Increased demand for electricity for EVs can make up for reduced demand due to rooftop solar power. All figures in TWh/yr. Source: own analysis based on [11].

3 Managing impacts of EV charging on the Costa Rican grid

EV charging can impact the electricity system by increasing the demand for electric energy, measured in kilowatt-hours (kWh), and increasing the peak demand for electric power, measured in kilowatts. The growth in energy demand could be met with the increased generation from solar DG, which has been estimated at 0.9 TWh in the same time frame, see Figure 16 [39], and with the availability of large untapped renewable energy sources, energy supply is not a constraint for electrification of Costa Rica’s transportation system.

The impact of EV charging will be more pronounced on peak power demand. As earlier discussed, the prevalence of detached homes in Costa Rica means home charging is likely to dominate even more here than in other countries, see Figure 13. Average daily round-trip commutes are less than 35 km, and the distance from the capital to main regional destinations is 100 to 240 km. Combined with the steadily increasing range of EVs (see Figure 17), this means Costa Ricans can safely be assumed to almost solely rely on over-night charging. The need for charging outside the home is reduced to road trips and for quick charging when required every now and then.

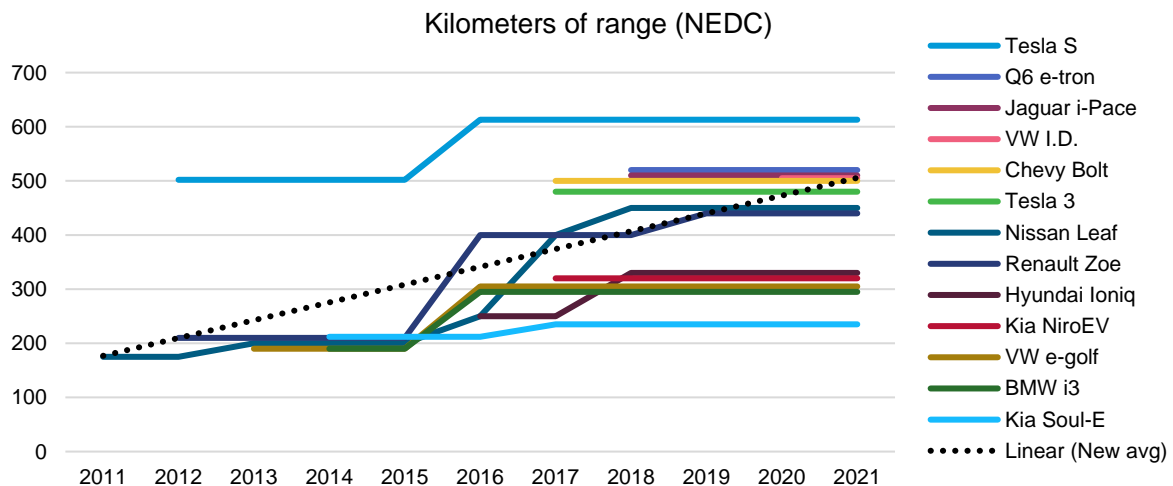


Figure 17: Driving range (km) of a sample of commercially available and announced battery-electric cars per the European test cycle (NEDC). Real-world range depends on driving style and weather, and is typically 25% lower. Source: own analysis based on auto manufacturers’ data.

3.1 Impact on peak power demand

Given the expected dominance of home charging, EV charging will mainly impact residential peak power demand [34]. For this analysis, reference is made to a British research project that monitored charging of 200 Nissan Leafs with 3.5 kW onboard chargers over 18 months. The project found that uncontrolled home charging on average increased individual homes’ evening peak demand by 1.2 kW [40]. Combining the typical demand curve of Costa Rica’s electricity system (bottom wedge in Figure 18) [11] with the EV

charging demand curve from the mentioned project, we find that peak demand increases the afternoon peak demand by 496 MW, up 32% from 1 572 MW (blue line in the figure).

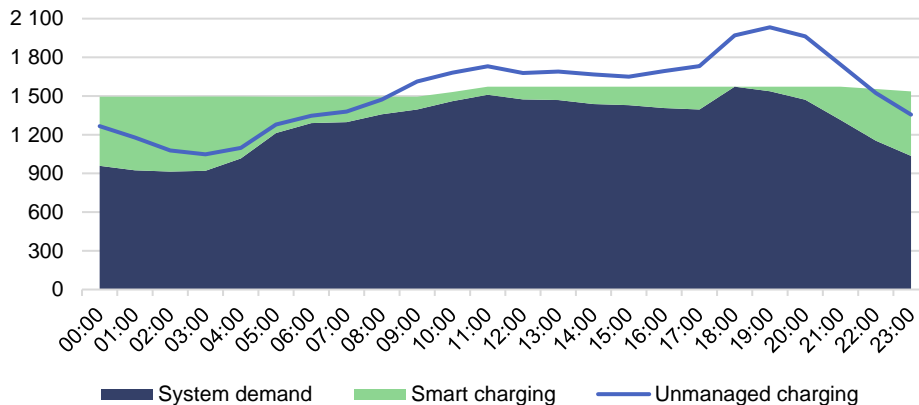


Figure 18: Costa Rican system demand curve (bottom wedge) with the projected impact of unmanaged EVs charging (blue line). The green wedge shows a time-optimized smart charging scheme. Source: Own analysis based on [11,40,41].

To meet the increased peak demand due to EV charging, electric utilities would traditionally build out grid infrastructure, the cost of which would be passed on to consumers through increased electricity tariffs [42]. International studies peg the cost of distribution grid reinforcements at around US \$1,250 per vehicle, or \$511 million for the 2030 EV deployment scenario discussed above [43]. Since Costa Rica’s current peak demand, 0.33 kW per inhabitant [11], is just 1/16th of the equivalent for leading EV markets such as Norway and Quebec, the reinforcement needs and costs will likely be higher in Costa Rica.

3.2 Strategies for smart residential EV charging in Costa Rica

A smart vehicle charging system would use the significant time flexibility offered by over-night EV charging at home away from the peak hours and still be able recharge the EVs in due time [42]. As the green wedge in Figure 18 shows, sufficient capacity is available below the system peak to supply the energy required by the ~410,000 EVs in the deployment scenario during off-peak hours. While achieving this perfectly optimized load shifting scenario would be difficult in practice, it clearly shows the potential for smart EV charging to avoid peak demand increase on the Costa Rican electricity system.

Smart home charging could be implemented by:

- EV drivers responding to price signals or
- Utilities or 3rd party service providers remotely managing the timing and power of charging in line with drivers’ requirements.

3.2.1 Driver-managed smart charging

Driver-managed smart charging means that EV drivers respond to price signals or other incentives from their electricity retailer to charge the vehicle in time periods when the grid has spare capacity, avoiding times of peak power demand.

In Costa Rica, the largest electricity distributor, CNFL, offers Time-of Use (ToU) rates to its residential customers, and the National Energy Plan calls for making such rates available for all residents [9]. ToU rates make it cheaper to charge during off-peak hours, see Figure 19. For example, night-time ToU rates, valid from 20:01 to 06:00, are currently 64% lower than flat rates and 83% lower than peak ToU rates [22]. This means nocturnal charging for 15 000 km would save around \$225 per year (see Figure 7) compared to flat electricity rates.

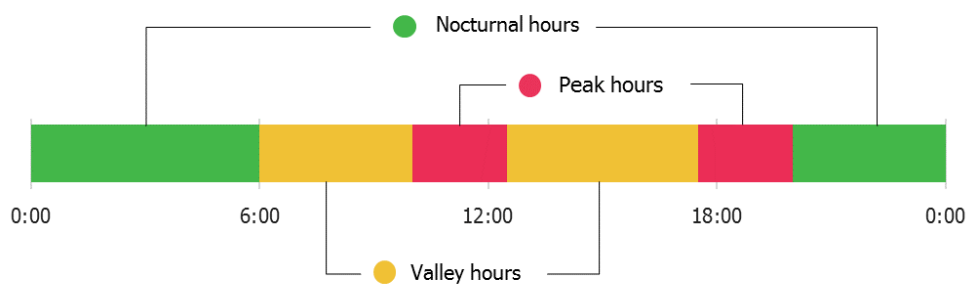


Figure 19: Peak, valley and night hours on the Costa Rican electricity grid. Source: [42].

ToU-based smart charging offers an early start to smart charging in Costa Rica without the need for new rate structures or regulations. However, it has two main draw-backs:

1. While 39% of Costa Rican residential energy consumers are currently offered ToU tariffs, only about 2% have taken advantage of them.
2. If large numbers of customers *were* to take advantage of ToU-tariffs for smart charging, it would likely create new peak demand events as large number of EVs start charging at the start of nocturnal rates, at 20:01. A US study involving 8,300 EVs found that home charging power demand grew seven-fold at the shift to nocturnal rates at midnight, see Figure 20 [44].

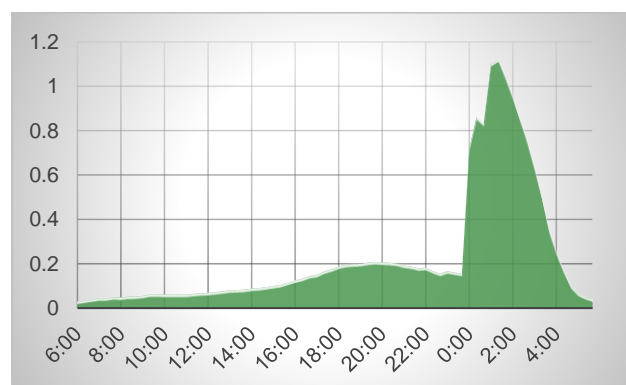


Figure 20: ToU tariffs can cause new peak load events. Source: [44].

3.2.2 Externally managed smart charging

To avoid the challenges of the driver-managed strategy, EV charging could instead be externally managed. This entails remotely scheduling and executing charging in a manner that delivers the required energy to the vehicle by the time required by the user, while enabling electricity grid operators to avoid or minimize charging during peak demand on the local and national grid.

The smart charging system could be managed directly by grid operators or by 3rd party aggregators acting on signals from the grid operator.

To implement a smart home charging system in Costa Rica, inspiration can be drawn from a growing body of international experience:

- Smart charging via cloud-connected vehicle platforms [45],
- connected home charging equipment controlled via the cloud [46],
- grid-connected home charging equipment controlled via the distribution grid [40], or
- hybrid systems combining cloud-connected charging equipment and vehicle-side data [47].

For grid planners and operators, externally managed smart charging can be a more certain and predictable tool for balancing supply and demand, avoiding blackouts, reducing the need for costly backup generators, avoiding extra investments in grid infrastructure and reducing wear on the grid. These cost savings would, depending on rate designs, benefit both EV owners and other users of the grid.

The main draw-back of the externally managed smart charging strategy is that it requires coordination between different stakeholders, e.g. EV users, grid operators, EVSE suppliers, vehicle OEMs and/or 3rd party smart charging service providers. While leveraging demand-side flexibility for cost-efficient balancing of supply and demand on the grid is expected to grow in importance in the coming years, the required regulatory and operational framework have not yet been implemented in Costa Rica [42].

3.3 Enabling smart home charging of electric vehicles in Costa Rica

What should policymakers and utilities do to facilitate home charging? Three key suggestions are made:

- **Help people charge at home:** Earlier work [42] found that Costa Ricans would like to get information and help on modern energy technologies from their electricity supplier. Costa Rican electricity suppliers should capitalize on this sentiment and offer to help their customers charge their vehicles at home. The electricity companies would also help themselves, since EV charging increases would increase revenues.
- **Gain experience** with smart home charging in the Costa Rican context. Important elements are technologies, user behaviors, grid impacts and possible incentive structures.
- **Adopt energy regulations for smart home charging:** Consider electricity rate designs, market mechanisms and business models to facilitate externally managed smart home charging, whether managed by electricity suppliers themselves or by 3rd parties.

4 Conclusions

We find that the conditions for electric mobility in Costa Rica are good, and that the country has the potential to quickly electrify its transport sector. By 2030, the scenario shows 410,000 light commercial and private EVs on the road, making up about one third of the expected fleet of such vehicles by 2030. This would reduce emissions by close to 1 million tons, about one third of Costa Rica's committed emission reductions, and reduce oil imports by \$175 million at current oil prices. Costa Rica's electricity grid is found to have advantageous features for supporting electrification, with large untapped renewable energy sources available. However, we showed that residential smart charging will be critical for mitigating adverse technical and economic impacts on the grid. Low existing demand means that smart EV charging is even more important in Costa Rica than in industrialized nations.

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