Electric Vehicle Charging at Telco Base Station and Bidirectional Charging at Hillslope Descent

Technical-commercial Cost-benefit Study and Scheduling-Reservation system

Adam Junid
Student Member
IEEE
adam.junid@ieee.org

Eng-Hwa Yap
Faculty of Engineering
University of Nottingham
Semenyih, Malaysia
EngHwa.Yap@nottingham.edu.my

Pek-Kim Ng
Faculty of Arts & Social Sciences
University of Nottingham
Semenyih, Malaysia
Pek-Kim.Ng@nottingham.edu.my

***Abstract*—Installing grid-connected photovoltaics (GCPV) at telecommunication company (Telco) base stations along highways, and providing electric vehicle (EV) charging facilities at strategic locations such as highway-side base stations offers a synergistic solution to both 1) displacing engine emissions using electricity from a renewable energy source, and 2) providing more highway EV charging stations for long distance EV driving. Strategically placed hillslope EV discharge stations would also offer EV users travelling downhill for long distances to sell their EV battery energy obtained from regenerative braking to the grid, freeing up the needed battery capacity to continue downhill with regenerative braking rather than losing it due to an already fully charged battery. This paper explores potential cost-benefits for investments in (i) highway-side Telco base stations with GCPV systems and EV charging stations as an additional source of revenue, and (ii) investments in EV discharge stations along hillslopes for EV users to sell battery energy from regenerative braking. The methodology used to gauge annual demand of new EV charge stations was by observation of existing highway-side EV charge station usage rates, estimating growth of EVs and charge stations, and reference to existing literature on EV charging tariffs, local electricity costs, and sizing/costing electrical equipment needed for the base station upgrade. To verify discharge kWh calculations from downhill descent regenerative braking, a downhill test drive of a Plug-in Hybrid Electric Vehicle (PHEV) was done. To discourage non-charging EVs remaining parked at charger units, a design framework involving remote charger unit monitoring, reservation, messaging and automated financial incentives is also presented.**

Keywords—EV charging; EV discharging; photovoltaics; Telco; base station

I. Introduction and Research Goals

The use of photovoltaics (PV) to charge Electric Vehicles (EVs) and Plug-in Hybrid Electric Vehicles (PHEVs) are considered a utopia for sustainable energy utilisation [1]. Due to falling costs of photovoltaics [2], capability of controlled EV charging to support/reduce peak demand [3]-[5], and profit opportunities for EV charging [6], [7], vertically integrated petroleum companies are also investing in public EV charging stations at retail petrol stations [8].

Telecommunication base stations owned and operated by telecommunication companies (Telcos), often located alongside major roadways and highways ([9] and Fig. 1), are electrically grid-connected, have an existing distribution cable route for ampacity upgrades, and have backup power supplies to ensure power during grid outages. It is proposed that roadside Telco base stations thus have existing locational and power equipment synergy to provide EV charging, whist earning the Telco another line of business profits.

Fig. 1. Map of Telco base station ID No. 5977 off northbound lane of North-South highway near Slim River, 100km north of Kuala Lumpur; taken from [9]. Inset: view of the Telco base station tower taken from [10].

An additional beneficial feature proposed for EV charging stations along downhill routes of long hillslopes is a discharging function, i.e. strategically located bidirectional charge stations. This would allow EVs that have fully charged batteries from downhill regenerative braking to discharge battery energy to the grid and/or local discharge station battery, freeing up EV battery capacity to allow continued use of regenerative braking for the remaining downhill journey. The discharge station would also earn revenue for the EV user, essentially from selling energy generated by the EV's downhill descent.

This paper firstly explores potential cost-benefits of Telco base station utilisation for EV charging. With a goal of maximising displacement of carbon emissions, grid-connected photovoltaics (GCPV) hypothetically installed at the base station identified in Fig 1 will be taken as a sample Telco base station design upgrade to EV charging capability. This base station was selected as an ideal location due to:

- Its convenient location about 100km northbound along the North-South Highway from Kuala Lumpur towards Ipoh and Penang, i.e. about halfway between the official range limit of the 20 – 24kWh usable capacity of first generation Nissan Leaf and Renault Zoe EVs.
- Proximity to 3-phase power supply at a substation about 900m away, also powering the Slim River Hospital.

Secondly, this paper explores potential cost-benefits from an EV discharge station hypothetically located along the downhill route from Resorts World Genting toward Genting Sempah. The change in elevation along this route's descent is shown in Fig. 2.

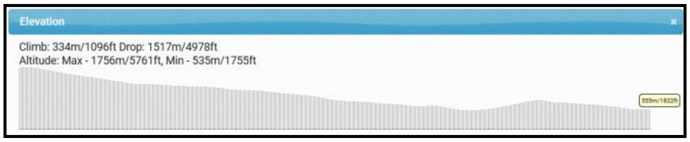

Fig.2. Elevation and descent gradient between Resorts World Genting and Genting Sempah, taken from [11]

Potential energy from Resorts World Genting Highlands descent to Genting Sempah		
Resorts World Genting Elevation	1756	m
Genting Sempah	555	m
Δh	1201	m
BMW 330e gross weight	1775	kg
g	9.8	m^2/s
mgΔh	30545620	Joules
Approx travel time	44	minutes
i.e.	2640	seconds
Ave Watts from descent	11570	W
i.e.	11.57	kW
Theoretical kWh from descent	8.48	kWh
50% capture	4.24	kWh
90% capture	7.64	kWh
4kWh discharge earnings at US$0.12/kWh	$0.48	
4kWh discharge earnings at US$0.49/kWh	$1.96	
7kWh discharge earnings at US$0.12/kWh	$0.84	
7kWh discharge earnings at US$0.49/kWh	$3.43	

Fig. 3. Estimation of EV/PHEV potential energy converted to battery kWh via regenerative braking, and possible discharge revenue [7] earned using example of a BMW 330e descending from Resorts World Genting toward Genting Sempah.

Fig. 4. Optimal location of discharge station using example of a BMW 330e descending from Resorts World Genting toward Genting Sempah taken from [15]. Inset: Retail petrol station, taken from [16], conveniently located adjacent to a rest/relaxation area, for EV/PHEV discharging and charging.

Using the change in elevation and vehicle gross weight, preliminary calculations shown in Fig. 3 indicate that a PHEV battery with 5.7 kWh usable energy, such as the one used on a 2016/7 BMW 330e, considering 50% to 90% charge conversion losses, would be fully charged from near empty between 17 km to 31 km downhill [12]-[14]. This makes the highlighted region in Fig. 4 an ideal location for a discharge station.

II. Literature Review

A. *Photovoltaic Use at Telco Base Stations*

There are already working, practical examples of photovoltaics supporting Telco base station power, e.g. [17] and [18]. Simulations by [19] and [20] have also indicated profitability from installing GCPV systems to support base station power demand, with resulting savings in electricity bill costs. However, as of this research paper's date (2017), Feed-in-Tariff (FiT) quotas offered by the Malaysian Sustainable Energy Development Authority (SEDA) for solar PV systems have been exhausted [21]. Hence, new GCPV installations are only cost-beneficial by supporting the electrical load of the installation's user, and can only earn income at regular tariff by exporting to the grid, provided there is a Net Energy Metering (NEM) agreement in place [22].

A sample Malaysian base station by [23] indicates each cabin may have two air conditioner units, which contribute to the average base station power demand of 4 kW indicated by [24]. It is thus noted that new GCPV installations for similar base stations in Malaysia without battery storage *and without a NEM agreement* should be less 4kWp, because generating more than this during peak sun intensity will export to the grid for free instead of offsetting base station demand.

There have been few published reports of actual savings from the installation of GCPV systems at Telco base stations, although [24] indicates that GCPV systems may have contributed in some way to reduce average base station electricity cost by 11% between 2008 – 2011

B. *Bidirectional Charging Station for EVs/PHEVs Operating at Hillslopes*

Bidirectional chargers [25] allow EVs/PHEVs to discharge their traction battery to power households. It also allows PHEVs/EVs to discharge kWh partway down hillslope descents, should its battery become full from regenerative braking during the descent.

The risk of losing EV regenerative braking once the battery has become full from downhill braking has been addressed by General Motors in their Chevrolet Bolt EV, where the user can set "Hilltop Reserve" charging to ensure the traction battery has sufficient empty capacity to provide regenerative braking during prolonged downhill descent [26].

The 2018 Nissan Leaf will also incorporate a "Hilltop Reserve" function. It is salient to note that users of older Nissan Leaf models have reported that driving downhill with a fully charged EV traction battery results in loss of motor/regenerative braking; a potential safety issue should the brakes start to fade [27].

Strategically placed discharge stations along hilltop descents will provide EV/PHEV users the option of discharging fully charged traction batteries without needing to operate in "Hilltop Reserve" mode, and getting paid for the kWh discharged to the grid or local battery energy storage. It is envisaged that the discharge station will have bidirectional charger(s), enabling it to also charge ascending EVs/PHEVs.

III. Methodology

The cost benefit methodology executed for Telco base station upgrades and hill slope bidirectional charge stations are described in [28]; namely, to estimate Net Present Value (NPV) and Internal Rate of Return (IRR).

A. Telco Base Station Upgrade to Grid-Connected Phtovoltaics and 22kWh Electric Vehicle Charger(s)

To obtain a 4kWp GCPV system capital cost, an averaged price for monocrystalline PV panels quoted by three Malaysia-based contractors [29], [30], [31] between 2014 – 2017 was taken, resulting in a cost of about US$8200 for a grid-connected 4kWp system. This Capex cost estimate figure is corroborated by [32]. US$3000 was taken as cost for a 22kW EV charger [7]. Local electricity tariff costs of USD0.11 per kWh were taken for the first 200kWh offtake, and USD0.12 per kWh for subsequent kWh units [33].

For 22kW charger(s), the Telco base station would also require a distribution system upgrade from single-phase to three-phase power. This calls for a three or four core cable from base station to nearest substation, about 900m away. Using nominal three phase voltage of 400V, and a total base station load 26kW including EV charger, solving for current in (1) yields about 44.2A.

$$P = pf \times \sqrt{3} \times V \times I \qquad (1)$$

where P is 26kW total load, pf is the power factor, taken as 0.85, V is 3-phase voltage, and I is 3-phase current.

Sizing the cable to this ampacity based on IEE Wiring Regulations for less than 2.5% voltage drop [34], a three or four core 185mm^2 cable would be sufficient for the three-phase system upgrade, budgeted at US$60 per meter [35]. Since the 185mm^2 cable is already slightly oversized and cables usually direct buried, cable derating factors to account for ground temperature and thermal conduction are relatively marginal and can be ignored. Cable burial labour cost of US$16 per meter is also included [36].

Another costing scenario involves use of 11kV local transformers sited locally at the base station to save on Low Voltage (LV) cable cost between base station and nearest substation. Two transformers are recommended to allow for single transformer shutdown maintenance while allowing continued use of the EV/PHEV chargers. Cost estimates include 11kV transformer [37]–[41], switchgear [42], LV switchboard [43], fault current protection [44], [45] and compact substation [46].

For both LV and 11kV costing scenarios, cabling for each charger, transformer and local switchboard/switchgear is allocated [47], [48]. Sizing of equipment, summarised in Fig. 5, took into account load diversity factors [49].

Estimations of Electrical Equipment sizing and cost to cater for EV / PHEV charging

22kW Chargers	Load demand (1)		11kV Transformer		11kV Switchgear (2), fault protection relay				3C 11kV cable, 900m		LV Switchboard and fault protection			4C LV cable		
Installed	kW	kVA	kVA	US$/unit	Running A	Rated A	3s Fault kA	US$/unit	mm²	US$/m	Running A, LV	Rated A, LV	US$/unit	mm²	US$/m	m allocated
1	26.0	30.6	50	$1,000	0.001	400	16	$5,300	16	$20	37.6	400	$756	10	$9	20
2	43.2	50.8	100	$1,500	2.270	400	16	$5,300	16	$20	62.4	400	$756	10	$9	25
4	82.8	97.4	100	$1,500	4.351	400	16	$5,300	16	$20	119.7	400	$756	10	$9	10
														16	$13	25
6	95.2	112.0	200	$3,000	5.003	400	16	$5,300	16	$20	137.6	400	$756	10	$9	10
														16	$13	10
														25	$18	25
8	126.0	148.2	200	$3,000	6.621	400	16	$5,300	16	$20	182.1	400	$756	10	$9	10
														16	$13	10
														25	$18	10
														35	$24	25
9	141.4	166.4	200	$3,000	7.430	400	16	$5,300	16	$20	204.3	400	$756	10	$9	5
														16	$13	10
														25	$18	10
														35	$24	10
														50	$34	25
10	156.8	184.5	200	$3,000	8.240	400	16	$5,300	16	$20	226.6	400	$756	10	$9	10
														16	$13	10
														25	$18	10
														35	$24	10
														50	$34	25
20	266.4	313.4	400	$5,800	13.999	400	16	$5,300	16	$20	385.0	800	$1,417	10	$13	20
														16	$13	20
														25	$18	20
														35	$24	20
														50	$34	50
60	794.4	934.6	1000	$12,560	41.745	400	16	$5,300	16	$20	1148.0	1600	$2,739	10	$13	20
														16	$13	20
														25	$18	20
														35	$24	20
														50	$34	50
														240	$166	150
100	1322.4	1555.8	1600	$16,200	69.490	400	16	$5,300	25	$30	1911.0	2400	$4,061	10	$9	100
														16	$13	100
														25	$18	100
														35	$24	100
														50	$34	250
														240	$166	250

Notes:

1) Includes diversity factor
2) Switchgear fault kA sizing and costing is preliminary and must be subject to confirmation via fault current and protection coordination studies
3) 10mm² cable ampacity 59A, 16mm² 79A, 25mm² 104A, 35mm² 129A. Each 22kW charger draws 31.8A
4) IEE voltage drop limit o 2.5% limits the 10mmsq cable length to 80m for each charger
5) Spacing of each charge unit stanchion taken as 2.4m, cable length to span this taken as 5m to allow for stanchion, bending radius, cable dressing

Fig. 5. Sizing and cost of equipment in the cost-benefit analysis and exercise. The different charger amounts were based on iterations in an effort to arrive at an optimal amount, based on predicted demand over 20-30 years

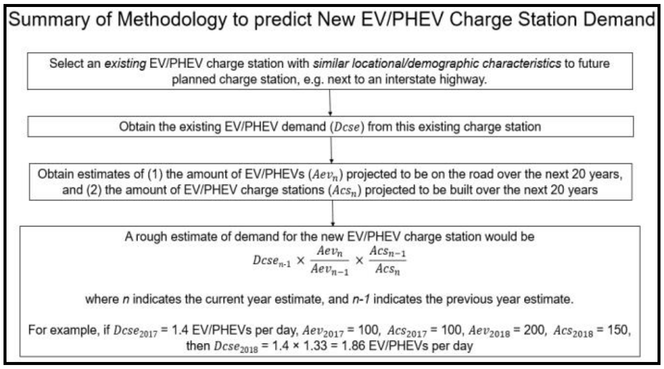

Fig. 6. Methodology to estimate EV/PHEV charge station annual demand

Utility connection charge [50] for three-phase power from nearest available substation is budgeted at US$2000 [51]. Competent person installation and testing labour costs are estimated at US$1500 for each transformer and Medium Voltage (MV) switchgear panel and US$800 for the entire LV switchboard [52]. Earthing installation and testing costs are taken to be US$700 [53].

The Telco base station will also require Capex for highway exit and entry ramps of lengths 162m and 366m respectively [54], translating to a cost of about US$1.06 million per km for double lane ramps (or a single lane with adjacent parking lane), or about US$0.53million per km for a single lane only [55].

Omitted from the cost estimates are any additional land acquisition costs, Goods and Services Tax (GST), concrete plinths, stanchions/hoods for chargers, lighting, and fees for design consultants, customs and freight forwarding.

To recoup the above investment, an estimate of charge station usage is required. As of this report's preparation, at least 10 EV/PHEVs have been observed using a highway-side EV station at Solaris Serdang, each vehicle remaining connected for at least two hours [56]. Conservatively taking each charge as a half-charge of a 20kWh EV, this translates to about 100kWh offtake per week. Applying the range of tariff rates per 10kWh willing to be paid by EV users surveyed by [7], this translates to between US$12.26 – US$49.04 revenue per week in 2017. This translates to US$0.13 – 0.49 per kWh, i.e. comparable to rates in other cities [57].

Allowing a year for construction, the upgraded base station GCPV and EV/PHEV charging would start earning revenue in 2019. Revenue from the GCPV system is calculated from [58]. An estimate of EV/PHEV demand is based on annual market share increases [59], [60] and cumulative amounts of EVs/PHEVs calculated predicted to be on the road, which in the Malaysian context will be based on the number of cars, vans and trucks currently registered in Malaysia [61]. Decommissioned vehicles were not taken into account for the annual cumulative estimates.

For the number of EV/PHEV units added annually to roads, the definition by [59] was taken, i.e. "EV" technically includes PHEVs.

For the number of "charge stations" nationwide, one charge station was literally taken to mean a single charger unit, including charger units bundled with EVs for home installation. No charge units were counted for PHEV sales. As of this study's date, charger units are not included in PHEV prices within Malaysia, only as an optional extra.

In addition to charger units bundled with new EVs, three charger units were taken to be installed per week at five locations annually. This is based on the author observing the construction of three PHEV charger units installed at Bangsar Shopping Centre in 2017, which took about a week, and the fact there are five major petrol/diesel distribution/retail companies in Malaysia.

A summary of the methodology to estimate annual charge demand is shown in Fig. 6.

Since the Telco base station and charge station will have GCPV, the monetary value of PV energy generated [58], based on existing and historical tariff escalation rates [62] will also be taken into account as annual revenue.

An IRR considered attractive to private sector investment is taken to be 12 – 18% [63].

B. *Bidirectional Charging Station for EVs/PHEVs Operating at Hillslopes*

Capital cost for a 60kW EV bidirectional charger, required for EV battery discharging, is taken as US$24000 [64]. Costs for three-phase cabling, utility connection charges and roadworks are ignored because there exists a convenient retail petrol station within the estimated location of optimal discharging (Fig. 4) that already has roadworks, ample parking space and a three-phase distribution system for the petrol station's retail air conditioning and pumps.

As of this study's date, there were no discharge stations or bidirectional charge stations installed in Malaysia, thus no usage data was found. However, analogous to the hypothetical charge station location shown in Fig. 1, the Fig. 4 location is also next to an interstate highway, and is thus taken to have a similar annual demand rate for charging EV/PHEVs.

A test drive of a rented BMW 330e PHEV was attempted downhill along the route indicated in Fig. 4 to verify the calculation results in Fig. 3.

The kWh generation results from the test drive were then added to revenue of a hypothetical bidirectional charge station to verify if the bidirectional charger investment would be cost-beneficial.

If found not cost-beneficial, an estimate could be done to gauge how much lower the bidirectional charger cost should fall to make it cost-beneficial.

IV. Findings

A. *Telco Base Station upgrading to Grid-Connected Phtovoltaics and 22kWh Electric Vehicle Charger(s)*

A comparison of Capex indicated that 11kV distribution between utility substation and charge station switchgear was preferable to LV distribution, i.e. the cost 11kV transformers, switchgear and 16mm^2 11kV cable cost less than the 900m 185mm^2 LV cable (Table I).

TABLE I: COMPARISON OF CAPEX FOR BASE STATION UPGRADE TO GCPV AND EV/PHEV CHARGING

Capex[a]	11kV distribution	LV distribution
Case of 20 charger units	US$467,050	US$480,604

[a] Excluding any land acquisition, GST, concrete plinths, stanchions/hoods, lighting, and fees for design consultants, customs and freight forwarding

Following Section IIIA's methodology, estimated EV/PHEV and charger unit numbers are shown in Fig. 7. NPV and IRR, shown in Fig. 8, indicate that NPV and IRR over 20 years are not cost-beneficial. Over 30 years, the investment maybe considered cost-beneficial; however, the use rate for each charger may not be practical because meeting the demand utilisation from 2040 onwards calls for increasing use of the charger at night (Table II), which may likely inconvenience users and/or result in charger unavailability due to already being in use. Increasing the number of chargers however, sacrifices NPV and IRR, making the investment undesirable again.

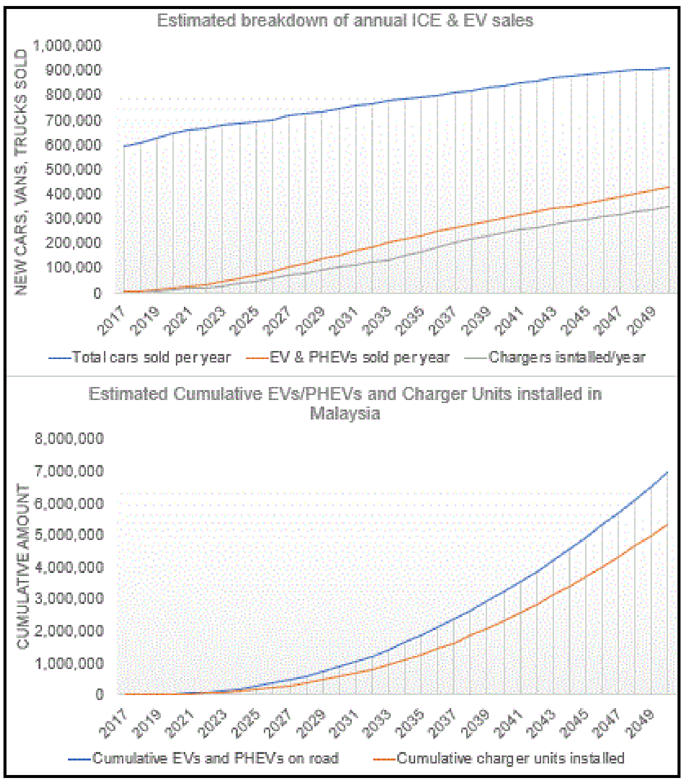

Fig. 7. Estimation of EV/PHEV and charger unit numbers.

TABLE II: ESTIMATION OF THE NUMBER OF TIMES A 22KW CHARGER IS USED FOR 1-2 HOURS OVER 24 HOURS

Year	2040	2050
Case of 20 chargers total	6.4	11.7

		Flat rate charge tariff, US$0.49 / kWh	Tariff escalations matching historical rate of petrol price increase	Flat rate charge tariff, US$0.49 / kWh, no GCPV	Tariff escalations matching historical rate of petrol price increase, no GCPV
Year	*kWh sold*	*Profit (US$)*	*Profit (US$)*	*Profit (US$)*	*Profit (US$)*
2018	0	-$467,050	-$467,050	-$458,850	-$458,850
2019	6,539	2,938	3,527	3,207	3,383
2020	8,907	4,493	5,269	5,067	5,300
2021	12,874	7,007	8,104	8,036	8,430
2022	18,391	10,545	12,086	12,214	12,835
2023	25,567	15,217	17,331	17,724	18,647
2024	34,689	21,230	24,066	24,807	26,117
2025	45,682	28,565	32,267	33,436	35,219
2026	57,118	36,350	40,941	42,568	44,850
2027	70,275	45,386	50,993	53,154	56,016
2028	84,959	55,560	62,296	65,062	68,576
2029	101,066	66,814	74,782	78,219	82,454
2030	118,470	79,072	88,363	92,534	97,553
2031	137,049	92,257	102,955	107,916	113,778
2032	156,760	106,344	118,527	124,335	131,096
2033	177,511	121,276	135,014	141,720	149,435
2034	197,619	135,905	151,139	158,726	167,372
2035	218,604	151,266	168,055	176,566	186,191
2036	238,310	165,873	184,108	193,497	204,049
2037	258,214	180,739	200,427	210,710	222,205
2038	278,241	195,813	216,955	228,143	240,593
2039	297,728	210,629	233,175	245,252	258,638
2040	317,140	225,512	249,446	262,417	276,742
2041	336,979	240,819	266,166	280,054	295,345
2042	357,215	256,532	283,313	298,144	314,425
2043	377,829	272,641	300,875	316,673	333,968
2044	398,805	289,141	318,845	335,633	353,965
2045	420,137	306,028	337,221	355,021	374,414
2046	441,821	323,306	356,003	374,839	395,317
2047	463,858	340,979	375,197	395,093	416,678
2048	486,253	359,056	394,810	415,789	438,507
	20 year NPV	($139,546)	($106,358)	($85,911)	($68,457)
	20 year IRR	9%	9%	10%	10%
	30 year NPV	$316	$47,990	$76,536	$102,861
	30 year IRR	12%	13%	13%	14%

Fig. 8. Estimation of revenue, NPV, IRR for Telco base station upgrade to have a 4kWp GCPV system and twenty 22kW EV/PHEV charger units. Historical petrol proce increases were taken from [65]. NPV is calculated based on a 12% discount rate.

A possible solution to minimize charger unit "idle hogging" is an online application or system (Fig. 9) that monitors, schedules and reserves ("books") available chargers, and imposes reasonable financial penalties on users who:

- Do not start using their reserved charger within an appointed time frame, (e.g. 15 minutes), or
- Do not remove their EV/PHEV once charging is complete (e.g. within 5 minutes).

Recommended design features for the charger reservation-sceduling system include:

- Not accepting a booking that exceeds a declared battery's kWh calculated charge duration;
- Charge card numbers required to make bookings, linked to the user's battery kWh;
- Messaging users about fines both five minutes before and after the fine is triggered;
- Fines per location adjusted just enough to deter abuse of charger bays, i.e. non-charging EV users parked at charge bays fined at rates significantly higher than the nearest parking alternative;
- Each charger having a suitable sensor to detect EV presence and vacation.

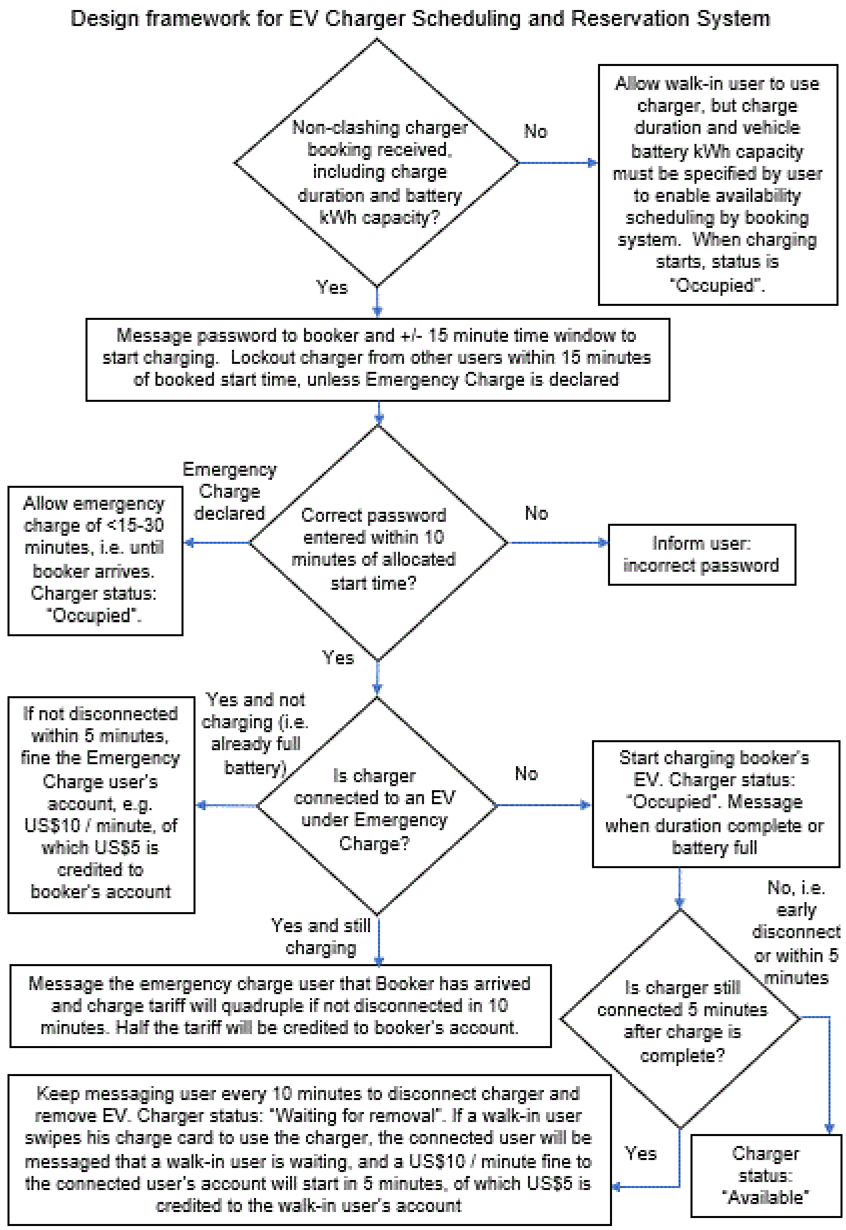

Fig.9. Design framework for EV Charger Scheduling and Reservation System.

As an alternative to automatically fining users for late EV removal, blocking other users, the system could apply a virtual tally of "karma points", e.g. 1 point if user disconnects/vacates within 5 minutes of completed charge, ramping proportionately to 5 points for vacation within 1 minute. If vacation is after a 5-minute grace period, one point is deducted per minute. Year-end points would be exchangeable for either EV charging credit or cash at rates based on predicted usage rates and/or available annual profit. Users with negative points will have credit deducted at that year's cash exchange rate.

B. Bidirectional Charging Station for EVs/PHEVs operating at hillslopes

Petrol/diesel filling stations already have three phase power systems to cater for peak load demand between 100kW - 1000kW [66]. A single 22kW charger can be added at minimal cost, e.g. US$8200 [8], and would be a beneficial investment even without charge tariff escalation, i.e. only petrol price escalation (Fig. 10, Genting Sempah case).

For the 5.7kWh PHEV downhill regenerative braking test drive, only about 1kWh was generated, based on the single bar out of six that appeared downhill at the Genting Sempah area. This could have been due to low profile tire friction, speed bumps that caused disc brakes to engage, and possibly the way the downhill route was designed: zig-zagging to maximise cornering friction. At 1kWh, most drivers may not bother to discharge at Genting Sempah; only charge, i.e. there would be no full-battery from regenerative braking safety reason to stop.

		1-Way 22kW Charger		Bidirectional Charger	
		Genting Sempah		Pikes Peak	
		4kWp GCPV	Charger only	80kW	_____kW
Year	kWh sold	Profit at US$0.49/kWh Flat rate	Profit at US$0.49/kWh Flat rate	Profit at US$0.49/kWh Flat rate	Profit at US$0.49/kWh Flat rate
2018		-$16,400	-$8,200	-$24,000	-$11,500
2019	5200	$2,390	$1,876	$2,577	$2,577
2020	5200	$2,412	$1,876	$2,577	$2,577
2021	5200	$2,435	$1,876	$2,577	$2,577
2022	5200	$2,459	$1,876	$2,577	$2,577
2023	5200	$2,485	$1,876	$2,577	$2,577
2024	5200	$2,511	$1,876	$2,577	$2,577
2025	5200	$2,539	$1,876	$2,577	$2,577
2026	5200	$2,567	$1,876	$2,577	$2,577
2027	5200	$2,597	$1,876	$2,577	$2,577
2028	5200	$2,628	$1,876	$2,577	$2,577
2029	5200	$2,661	$1,876	$2,577	$2,577
2030	5200	$2,695	$1,876	$2,577	$2,577
2031	5200	$2,731	$1,876	$2,577	$2,577
2032	5200	$2,768	$1,876	$2,577	$2,577
2033	5200	$2,806	$1,876	$2,577	$2,577
2034	5200	$2,847	$1,876	$2,577	$2,577
2035	5200	$2,889	$1,876	$2,577	$2,577
2036	5200	$2,932	$1,876	$2,577	$2,577
2037	5200	$2,978	$1,876	$2,577	$2,577
2038	5200	$3,026	$1,876	$2,577	$2,577
NPV		$2,402	$5,190	-$4,240	$6,921
IRR		14%	22%	9%	22%

Fig.10. Estimation of revenue, NPV, IRR for Telco base station upgrade to have a 4kWp GCPV system and twenty 22kW EV/PHEV charger units. Flate rate charge tariff is US$0.49/kWh. NPV is based on a 12% discount rate.

Possibly a more feasible case would be the 4267m Pikes Peak downhill drive [67]. Roughly four times the drop of Fig. 4's drive, it could possibly charge the 5.7kWh PHEV battery to near full. A hypothetical full revenue-to-discharge station owner estimate is shown in Fig. 10 (Pike's Peak case), where the fraction of PHEVs to EVs using the charger is taken as 27.5%. The discharge revenue does not justify the additional cost of the 80kW bidirectional charger however; it would have to drop to less than half its existing price to be cost-beneficial.

V. Conclusions and Recommendations

Telco base station modifications to have GCPV systems and EV charge stations may be cost-beneficial over a 30-year period. Where possible, higher kW chargers and charger status monitoring and reservation software involving financial incentives should be used to minimize time wastage caused by EVs/PHEVs fully charged but remaining parked at charger units, causing charger unavailability to other users.

Downhill descent discharge stations with bidirectional chargers are not cost-beneficial in Malaysia due to relatively low elevations of mountain driving routes there. It may be cost-beneficial at other countries having higher elevation mountain drive routes.

Due to varying distribution systems, substation proximities and FiT quotas, cost-benefit studies and decision-making for EV charging projects should be done on a case-by-case basis. For sites studied in this paper, adding a GCPV system to contribute energy for EV charging actually reduces project financial attractiveness (Figs. 8 and 10). In the interest of increased carbon emissions displacement from the transportation sector, energy security, and monetisation of available line-of-sight to sun area, it is suggested that EV charge station projects with GCPV systems be given incentives such as tax exemptions and higher FiT rates.

Acknowledgment

The authors thank Junid Saham for funding PHEV rental, and Adilah Junid for the idea of local battery storage at remote hillslope discharge stations to charge ascending EVs/PHEVs.

References

[1] Bhatti, Abdul Rauf, Zainal Salam, Mohd Junaidi Bin Abdul Aziz, Kong Pui Yee, and Ratil H. Ashique. "Electric Vehicles Charging Using Photovoltaic: Status and Technological Review." *Renewable and Sustainable Energy Reviews* 54, no. Supplement C (February 1, 2016): 34–47. https://doi.org/10.1016/j.rser.2015.09.091

[2] Shahan, Zachary. "Solar Panel Cost Trends (Tons of Charts)." CleanTechnica, September 4, 2014. cleantechnica.com/2014/09/04/solar-panel-cost-trends-10-charts/

[3] NREL. "Distributed Solar Photovoltaics for Electric Vehicle Charging: Regulatory and Policy Considerations," 2014. www.nrel.gov/docs/fy14osti/62366.pdf

[4] Parkinson, Giles. "UBS and Citigroup Expect Massive Solar-EV Revolution." *EnergyPost.Eu* (blog), 2014. energypost.eu/ubs-citigroup-warn-investors-massive-revolution-energy-industry/

[5] Renault. "Smart Charging: A Fleet of Renault Electric Vehicles Charged at Lowest Electricity Cost." Accessed December 19, 2017. group.renault.com/en/news/blog-renault/smart-charging-a-fleet-of-renault-electric-vehicles-charged-at-lowest-electricity-cost/

[6] Reuters. "Energy Firms Battle Startups to Wire Europe's Highways for Electric Cars." *The Star Online*, 2017. www.thestar.com.my/tech/tech-news/2017/09/15/energy-firms-battle-startups-to-wire-europes-highways-for-electric-cars

[7] Junid, Adam. "A Study of Electric Vehicle Charging Station Installation Progress in Malaysia." Scribd. Accessed December 19, 2017. www.scribd.com/document/339649997/Technical-English-Project-A-Study-of-Electric-Vehicle-Charging-Station-Installation-Progress-in-Malaysia-19jan16-R5

[8] Johan, Rizal. "Petronas Aims to Set up to 66 Charging Stations." *The Star Online*, 2017. www.thestar.com.my/business/business-news/2017/03/10/charge-your-ev-at-petronas-petronas-aims-to-set-up-66-charging-stations/?t=123

[9] Cellmapper. "Telco Base Station Northbound ID 5977 Owned by Maxis." Latitude 3.8366997759299686, Longitude 101.40940511941905, Slim River, Malaysia, 2013. https://www.cellmapper.net/

[10] Google. "North-South Expy, Slim River, Perak by Google Inc Street View - Aug 2017" coordinates 3.8419689,101.4105649, 2017. www.google.com/maps

[11] ElevationMap.net. "Elevation of Genting Sempah Malaysia with Altitude and Height." Accessed December 25, 2017. http://elevationmap.net

[12] Mottski82. "Regenerative Braking and Driving Downhill," 2013. http://www.mynissanleaf.com/viewtopic.php?f=27&t=13248&sid=45ece732872c340d32c501a424def82e&start=10

[13] mspohr. "How Much Charge Does Regen Braking Put Back in the Battery?" Tesla Motors Club, 2013. https://teslamotorsclub.com/tmc/threads/how-much-charge-does-regen-braking-put-back-in-the-battery.69255/

[14] Solberg, Greg. "The Magic of Tesla Roadster Regenerative Braking," 2007. www.tesla.com/blog/magic-tesla-roadster-regenerative-braking

[15] ElevationMap.net. "Elevation of Genting Sempah Malaysia with Altitude and Height." Accessed December 25, 2017. http://elevationmap.net.

[16] Google. "Bentong, Pahang: Photo by Google, Inc. Street View - Nov 2013." Google Maps (GPS coordinates 3.3520276,101.7907165), 2013. https://www.google.com.my/maps/

[17] Cellstrom. "Solar Powered Telecom Base Station," 2017.

[18] GEC, MOEJ. "Hybrid Power System; Solar and Diesel for Mobile Base Station in Offgrid Area MOEJ JCM Feasibility Study," 2013. www2.gec.jp/gec/en/Activities/fs_newmex/2013/2013fs04_rep.pdf

[19] Ike, Dike U., Anthony U. Adoghe, and Ademola Abdulkareem. "Analysis Of Telecom Base Stations Powered By Solar Energy." *International Journal of Scientific & Technology Research* 3, no. 4

(April 2014). http://www.ijstr.org/final-print/apr2014/Analysis-Of-Telecom-Base-Stations-Powered-By-Solar-Energy.pdf
[20] Pande, Geetha. "A Case Study of Solar Powered Base Stations." University of Gävle, 2009. https://www.diva-portal.org/smash/get/diva2:234252/FULLTEXT01.pdf.
[21] SEDA. "Solar PV: Available MW Installed Capacity for FiT Applications," 2017. seda.gov.my
[22] Publicover, Brian. "Malaysia Releases Net Metering Guidelines." PV Magazine International, 2017. https://www.pv-magazine.com/2017/05/08/malaysia-releases-net-metering-guidelines/.
[23] Molon, Alfred. "Telecommunications Tower with Antennas." Photo Blog, 2014. www.molon.de/galleries/Malaysia/Sarawak/Batang_Ai/Misc/img.php?pic=6
[24] Maxis. "Sustainability Report 2010/2011," 2011. https://www.maxis.com.my/content/dam/maxis/en/about-maxis/corporate-responsibility/sustainability-reports/sustainability-report-2010-2011.pdf
[25] Lambert, Fred. "Electric Vehicle Smart Charging to Go Nationwide in the Netherlands, Taking Advantage of Solar and Wind Energy." *Electrek* (blog), 2016. https://electrek.co/2016/10/18/electric-vehicle-smart-charging-to-go-nationwide-in-netherlands/
[26] chevybolt.org. "Only Charging in Hilltop Reserve, Cons?," 2017. http://www.chevybolt.org/forum/82-charging-batteries/18746-only-charging-hilltop-reserve-cons.html
[27] Jimmychopps. "Regenerative Braking and Driving Downhill." *mynissanleaf.com*, 2013. http://www.mynissanleaf.com/viewtopic.php?t=13248
[28] European Commission. "Guide to Cost-Benefit Analysis of Investment Projects." Brussels, Belgium, 2015. ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf
[29] Lau, Johnson. "Solar Naturally," 2014.
[30] NRJ, Solar. "Residential Solar," 2016. http://www.solarnrj.my/residential-solar.html
[31] Wong, C.P. "Contact Us - Submission," October 17, 2017.
[32] Sher Mohamad, Ali Askar. "Challenges in Collecting Renewable Cost Data in Malaysia." 2014. http://www.irena.org/-/media/Files/IRENA/Agency/Events/2014/Dec/12/8-SEDACollectingcostdataSEAsia.pdf?la=en&hash=E0BAEAAB3F167EDE0992C7937894A911A63049BD.
[33] TNB. "Electricity Tariff Schedule," 2014. https://www.tnb.com.my/assets/files/Tariff_Rate_Final_01.Jan.2014.pdf
[34] CSE. "Voltage Drop Calculations." CSE Industrial Electrical Distributors, 2016. https://www.cse-distributors.co.uk/cable/technical-tables-useful-info/voltage-drop-calculations/
[35] Shanghai Shenghua Cable Group Co. "185mm Cable," 2017. https://www.alibaba.com/showroom/185mm-cable.html
[36] medlinroad. "[Cable] Cost of Underground Install - Cable & Satellite TV | DSLReports Forums." *DSL Reports*, 2015. www.dslreports.com/forum/r26898488-Cable-cost-of-underground-install
[37] Beijing Daelim Green EP Tech. "50kVA Transformer," 2017. https://www.alibaba.com/showroom/50kva-transformer.html
[38] Shanghai Yewan New Energy Technology Company. "100kVA Transformer," 2017. https://www.alibaba.com/showroom/100kva-transformer.html
[39] Jiangshan Transpower Enterprise. "Transformer 200kVA." Accessed December 26, 2017. www.alibaba.com/showroom/transformer-200kva.html
[40] Hebei SUN Electric Power Transformer. "1500kVA Transformer Price." Alibaba, 2017. https://www.alibaba.com/showroom/1500-kva-transformer-price.html
[41] Shanghai Baocheng Electrical Hardware Factory. "2500kVA Transformer Price," 2017. https://www.alibaba.com/showroom/2500-kva-transformer-price.html
[42] Xi'an Xigao Electric Energy Group. "Medium Voltage Switchgear," 2017. alibaba.com/showroom/medium-voltage-switchgear.html
[43] Shanghai Zhenda. "Low Voltage Switchboard," 2017. https://www.alibaba.com/showroom/low-voltage-switchboard.html
[44] ABB. "Electrification Products Price List." ABB, March 16, 2016. systemcontrols.co.in/pricelist/ABB_PRICELIST_2016_16.03.2016.pdf
[45] GE. "345 Transformer Protection Relay." GE Digital Energy, 2017. http://store.gedigitalenergy.com/ViewProduct.aspx?Model=345
[46] Sichuan Yituo Electrical Appliance Manufacture. "Electrical Substation." Alibaba.com, 2017. https://www.alibaba.com/
[47] Hebei Dagang Cable. "Electric Aluminum Cable 16mm 3 Core 11kV 15kV 33kV Cable Xlpe Price Medium Voltage Power Cable Manufacturer," 2017. alibaba.com
[48] Hongliang Cable. "4C 10mm PVC Cable," 2017. alibaba.com
[49] IEC. "Electrical Installation Guide According to IEC International Standards: Factor of Simultaneity for Distribution Boards." Scnheider Electric, 2008. https://www.schneider-electric.pl/documents/Polish_Catalogue/Technical/eig.pdf
[50] TNB. *Electricity Supply Application Handbook*, 2011. https://www.tnb.com.my/assets/files/ESAHv3.pdf
[51] Ooi, Rick. "3-Phase Wiring," 2013. https://forum.lowyat.net/topic/691458/+420
[52] HomeAdvisor. "Learn about the Cost of Projects in the Electrical Category." Electrical Work & Repair Costs, 2017. https://www.homeadvisor.com/cost/electrical/
[53] buildingsherrif.com. "Average Labour Cost/Price of Electrics." The Building Sherrif, 2017. http://www.buildingsheriff.com/electrics-installation-costs.html
[54] sddot.com. "Chapter 13 - Interchanges." In *Road Design Manual*. South Dakota Department of Transportation. Accessed December 25, 2017. http://www.sddot.com/business/design/docs/rd/rdmch13.pdf
[55] Elswick, Frank. "How Much Does It Cost To Build A Mile Of Road?" Midwest Industries, January 5, 2016. http://blog.midwestind.com/cost-of-building-road/
[56] Kamal. Interview with Petronas Dagangan counter staff observing the ChargeEV station, Serdang, December 25, 2017.
[57] Blank, Mindy, and Kevin B. Jones. "Electric Vehicle Charging: Tariffs and Tradeoffs." Fortnightly, 2015. https://www.fortnightly.com/fortnightly/2015/03/electric-vehicle-charging-tariffs-and-tradeoffs
[58] National Renewable Energy Laboratory. "PVWatts Calculator." NREL, 2017. http://pvwatts.nrel.gov/
[59] Bloomberg New Energy Finance. "Electric Vehicles to Be 35% of Global New Car Sales by 2040." Bloomberg New Energy Finance, February 25, 2016. https://about.bnef.com/blog/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/
[60] Sahari, M. Madani, Hashim Helme, Zainal Abidin Ahmad, Ishak Aris, Ahmad Zainal Abidin, Mohd Nazmi Mohd Nur, Nurul Fateha Aziz, et al. "Automotive Industry Sector." Akedemi Sains Malaysia, 2016. akademisains.gov.my/download/ms3.0/Automotive_Industry_Sector.pdf
[61] Lee, Jonathan. "Vehicle Registrations in Malaysia Hit 28.2 Million Units." *Paul Tan's Automotive News* (blog), 2017. paultan.org/2017/10/03/vehicle-registrations-in-malaysia-hit-28-2-million-units/
[62] Unitedmy. "Malaysia Electricity Tariff Increased 26% from 2008 to 2014," 2014. unitedmy.com/2014/05/malaysia-electricity-tariff-bill-2008.html.
[63] Kronman, George E., Don B. Felio, Thomas O'Connor, and Mindy S. Kronman. "Key Components of E&P in the Global Marketplace." In *International Oil and Gas Ventures: A Business Perspective*. American Association of Petroleum Geologists, 2000. https://pubs.geoscienceworld.org/books/book/1296/chapter/107152167/Key-Components-of-EampP-in-the-Global-Marketplace
[64] Parwa Technology. "Bidirectional DC Power Supply for Testing Electric Vehicle Motor," 2017. parwa.en.alibaba.com/product/60323263130-221462440/Bidirectional_DC_Power_Supply_for_testing_electric_vehicle_motor.html
[65] Cilisos. "Petrol Prices in Malaysia," 2014. https://cilisos.my/wp-content/uploads/2014/10/Petrol-prices-1990-2014.jpg
[66] Caviar, and Flood. "What Size Generator Does It Take to Run a Gas Station?," 2012. http://ask.metafilter.com/228150/What-size-generator-does-it-take-to-run-a-gas-station
[67] coloradosprings.gov. "Pike's Peak - America's Mountain," 2017. https://coloradosprings.gov/ppam