Environmental Impacts of Utility-Scale Battery Storage in California

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***Abstract* — Battery storage is an emerging solution to increase renewable penetration to the grid by using surplus daytime solar generation to meet evening peak electricity demand, thereby reducing solar curtailment and the need for ramping of natural gas marginal generation. Based on life cycle environmental impact assessment, utility-scale Li-ion battery storage has significantly lower impacts than natural gas power in four out of six environmental impact categories assessed (climate change, fine particulate matter, photochemical ozone formation, and terrestrial acidification). Implementing utility-scale battery storage through 2030 can reduce CO_2e emissions from California's electricity sector by 8 percent (15.5 million tonnes CO_2e on a life cycle basis) compared to exclusively using natural gas power to back up solar. Therefore, utility-scale battery storage has the potential to reduce the climate change and air pollution impact of California's electricity sector, while increasing solar electricity grid penetration through improved grid flexibility.**

***Index Terms* — Lithium batteries, power grids, energy storage, solar power generation.**

I. INTRODUCTION

Energy storage can be used to store surplus electricity and bridge intermittency gaps by discharging stored electricity onto the grid when electricity demand is high. The recent and projected increase in solar and wind generating capacity in California (Fig. 1) has led to a strong push for the development of energy storage technologies. If implemented on a large scale, electricity storage could help improve grid flexibility and allow greater penetration of solar electricity on the grid ("flexible solar") [1].

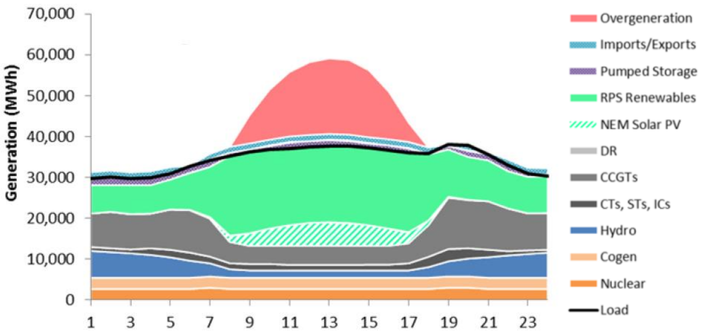

Fig. 1. Forecasted hourly generation mix and load in California during an April day in 2030 given 50% renewable portfolio standard [2].

To support electricity storage deployment, California passed legislation in 2010 requiring the state's three largest investor-owned utilities (PG&E, SCE, and SDG&E) to procure 1,325 MW of electricity storage (not including large-scale pumped hydro storage) by 2020. As of 2018, these California utilities have procured or are seeking approval to procure nearly 1500 MW of electricity storage, much of which is battery storage [3].

The first objective of this study was to quantify the environmental impacts of utility-scale Li-ion battery energy storage systems (BESS) compared to natural gas power for delivering grid electricity. Secondly, deployment was considered over a 14-year period (2016-2030) to determine the cumulative environmental impacts of using natural gas power to back up (meet undergeneration by) solar, with and without utility-scale battery storage as a complementary technology. Note when this study was initiated, California's 2030 renewable portfolio standard (RPS) was 50% and this target is used in this study, though California's 2030 RPS is updated to 60% effective 2019.

II. METHODS

Regarding the first study objective, life-cycle assessment (LCA) was conducted with GaBi ThinkStep software and Ecoinvent (V. 3.0) unit processes, using a functional unit of 1 MWh of electricity generated. The utility-scale Li-ion BESS life cycle inventory (LCI) was based on PV microgrid system LCI data for the Li-ion battery [4] and BESS balance of system [5] with specifications shown in Table I. This project assessed environmental impacts based on six environmental indicators (climate change, terrestrial acidification, photochemical ozone formation, particulate matter formation, human toxicity, and freshwater eutrophication) selected from ReCiPe 2016 [6].

Table I. Li-ion BESS Specifications

Category	**Quantity**	**Unit**
Battery energy density	112	Wh/kg
Battery lifetime	20	Yrs
Discharge rate	1	daily
Cycle life	7,300	cycles
Round trip efficiency	90	%
Depth of discharge	80	%

Category	Quantity	Unit
Parasitic loss factor	1	%
Battery power rating	1.4	MW
Inverter	3.36	500 kW
Transformer	5,124	Kg
Concrete	10,600	kg
Concrete lifetime	40	Yrs
Steel	5,460	kg
Steel lifetime	40	yrs

To fulfill the second objective of understanding the long term environmental consequences of using utility-scale battery storage, this project compared two scenarios for meeting California's future energy demand through 2030 (Fig. 2).

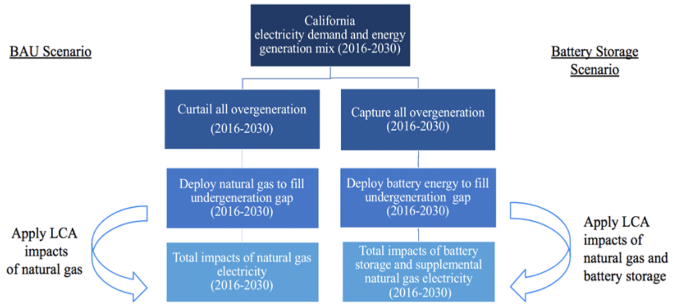

Fig. 2. Business as usual and battery storage scenarios (2016-2030)

A. Business As Usual (BAU) - No Battery Storage Scenario

This scenario assumes evolution of California's energy generation mix over the 14-year time frame, with increasing renewable deployment to meet the California's RPS mandate in 2030. Solar electricity generated during the day is dispatched to the grid to meet electricity demand, with any excess solar production curtailed. As solar generation declines in the evening, natural gas electricity is deployed to meet peak electricity demand.

B. Battery Storage Scenario

This scenario assumes the same evolution of California's energy generation mix as the BAU scenario, except for the addition of battery storage and associated reduction of natural gas generation (Fig. 3). Solar electricity generated during the day is used to meet electricity demand. However, in contrast to the BAU scenario, excess solar energy is stored in a BESS instead of being curtailed. In the evening, when solar generation declines as peak electricity demand occurs, energy stored in the BESS is discharged to the grid to meet demand. If there is any additional electricity demand after the BESS has been discharged (undergeneration), the remaining demand is met by natural gas electricity. The 2030 battery storage contribution in Fig. 3 is based on the estimated renewable overgeneration in that year, with battery storage used to avoid curtailment.

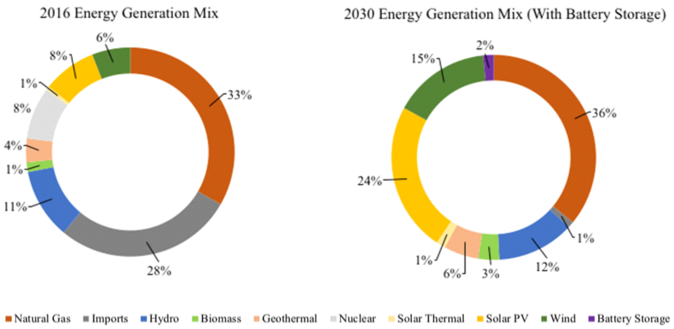

Fig. 3. Comparison of California's actual 2016 energy generation mix with the projected 2030 energy generation mix under the battery storage scenario (based on [2][3][7]). (Note that 2030 BAU scenario has 38% natural gas and 0% battery storage, but is otherwise the same as 2030 battery storage scenario in this figure.)

III. RESULTS

The life cycle environmental impacts per MWh from the Li-ion BESS and from natural gas power were estimated for each of the six environmental impact categories (Fig. 4). The BESS had significantly lower environmental impacts in four categories (climate change, fine particulate matter, photochemical ozone formation, and terrestrial acidification), all of which are indicators of air pollution or climate. In one impact category (freshwater eutrophication), the BESS showed a significant increase in impact compared to natural gas power, due to the raw material and production of the battery, particularly the integrated circuit board of the battery management system. However, the magnitude of freshwater eutrophication impacts in Fig. 4 are minor in comparison to the agricultural sector [8].

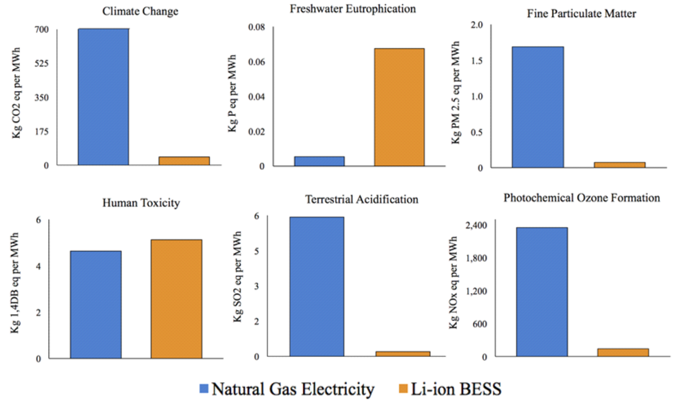

Fig. 4. Life cycle environmental impact per MWh of natural gas power and Li-ion BESS

Based on the LCA results, implementing utility-scale battery storage can significantly improve air pollution and climate indicators compared to natural gas power. To determine the cumulative environmental impacts of deployment through 2030, the LCA results were applied to the BAU and battery storage scenarios in Fig. 2.

In the BAU scenario, the LCA impacts of natural gas power were multiplied by the total MWh of undergeneration (*i.e.*, all undergeneration by solar was met by natural gas electricity; Fig. 5). In the battery storage scenario, the LCA impacts of the Li-ion BESS were multiplied by the MWh of battery output (Fig. 5), which was calculated from the total MWh of overgeneration by solar and the battery degradation characteristics. Since the battery storage output was not enough to fully back up solar, supplemental natural gas electricity was required to meet the undergeneration gap in the battery storage scenario.

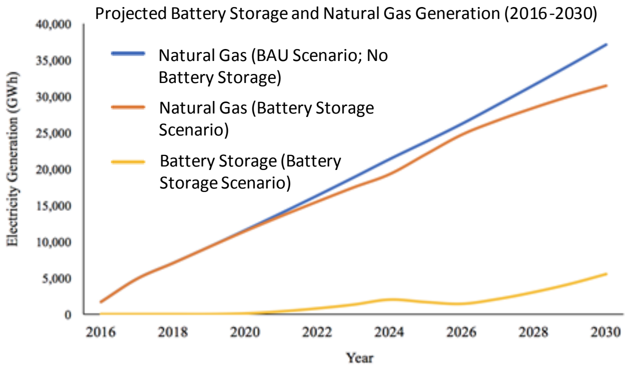

Fig. 5. Projected annual electricity generation (2016-2030) from natural gas power used to back up solar, without and with battery storage (BAU and battery storage scenarios, respectively; see Fig. 2).

As shown in Fig. 6, using battery storage with supplemental natural gas from 2016 to 2030 could reduce the climate change impact of the BAU scenario by 8 percent, corresponding to an avoidance of 15.5 million tonnes CO_2e emissions over the 14-year timeframe on a life cycle basis.

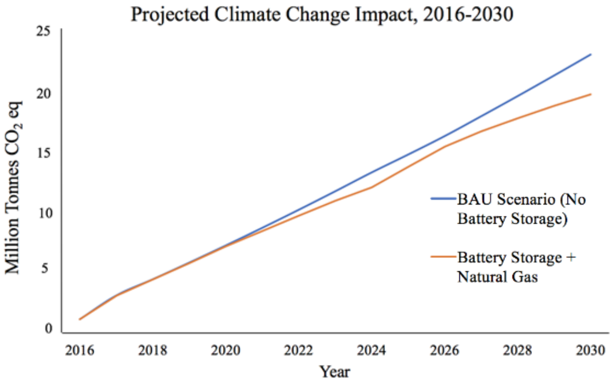

Fig. 6. Projected annual CO_2e emissions (2016-2030) from natural gas power used to back up solar, without and with battery storage (BAU and battery storage scenarios, respectively; see Fig. 2).

IV. CONCLUSION

Utility-scale battery storage has the potential to reduce the climate change and air pollution impact of California's electricity sector, while increasing solar electricity grid penetration through improved grid flexibility.

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