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Abstract: *As the City of Austin, Texas, continues to face climate change, it has adopted a goal to reach net-zero community emissions by 2040, and Austin Energy, the City's municipal electric utility, has set plans to increase renewable energy production and consumption in line with this net-zero goal. While these plans acknowledge that there are health and equity consequences to the continued use of fossil fuels for electricity production, this paper seeks to quantify benefits that are often unaccounted for when considering renewable energy plans, such as the economic contributions from green job creation and improved human health. Better understanding these benefits can help city leaders comprehend the value and importance of transitioning to renewable energy for a cleaner and more sustainable future.*

Keywords: Co-benefits; Renewable Energy; Solar PV; Energy Policy

1. INTRODUCTION

1.1 Austin's Climate & Renewable Energy Situation

The city of Austin, Texas, like many other cities across the world, is beginning to cope with the effects of climate change, while also attempting to mitigate them. In addition to changing cold weather and precipitation patterns, Austin's already hot, humid subtropical climate will continue to get hotter, with the heat index expected to rise 2–10°F, temperatures reaching or surpassing 110°F more frequently, and the number of heatwaves doubling [1]. As heat becomes more extreme in Austin due to climate change, the use of air conditioning will be more pronounced and increasing energy demand.

At the same time, Austin has experienced rapid growth. Since 2010, the population of the Greater Austin Metropolitan Statistical Area (MSA) has grown by 36% and, for twelve consecutive years, experienced the highest growth of any major metropolitan area in the United States (falling to second place in 2023) [2]. As population grows, energy demands will also likely increase. Also, as Austin seeks to reduce transportation emissions, currently the largest source of emissions for the city, an increase in electric vehicles may also have an impact on energy demand.

While energy generation is one of Austin's largest sources of emissions, in 2021, the Austin City Council adopted the Austin Climate Equity Plan, which sets a "bold and aggressive goal of equitably reaching net-zero community-wide greenhouse gas emissions by 2040" [3]. This plan works in tandem with several others throughout the City, including the "Resource, Generation and Climate Protection Plan to 2030 (2030 Plan)" set forth by Austin Energy, the City's municipally-owned energy utility, to achieve this net-zero goal. The 2030 Plan sets out goals to increase renewable energy production and consumption, moving away from carbon-emitting sources, in order to continue meeting energy demand while also moving towards the goal of net-zero emissions.

In 2022, the Austin City Council directed Austin Energy to work with the Electricity Utility Commission (an entity designated to oversee Austin's energy utility) to update the 2030 Plan. The Electricity Utility Commission (EUC) created the Resource Planning Working Group with several public energy sector and community stakeholders to provide leadership, guidance, and recommendations. This group's recommendations culminated in the 2024 document: "Austin Energy Resource, Generation and Climate Protection Plan to 2035" (2035 Plan).

One key component of the 2035 Plan, is the development of local solar photovoltaic (PV) power throughout the city. As the 2035 Plan mentions, there is limited space within the city, so rooftop solar is recommended over larger solar farms. The 2035 Plan lays out three goals for additional solar capacity for the city [4]:

1. 350 MW Solar by 2027.
2. 500 MW Solar by 2030.
3. 700 MW Solar by 2035.

1.2 Research Gaps and Contributions

The 2035 Plan also acknowledges that the benefits of increasing renewable energy, such as solar, and moving away from fossil fuel-based energy generation expand beyond efforts to reduce greenhouse gas (GHG) emissions, stating "Numerous studies have established that the financial and human costs of climate change, air pollution and water pollution far outweigh any benefits from continued use of fossil fuel energy sources," citing the climate and energy nonprofit RMI (Rocky Mountain Institute)'s article titled "The Hidden Health Costs of Gas-Fired Power Plants" which looks broadly at health and equity impacts of energy generation emissions across the U.S. [5] The equity implications are especially important when considering that marginalized communities often bear the brunt of harm resulting from burning fossil fuels in Austin. Moreover, as the title suggests, equity is a key pillar of the Austin Climate Equity Plan, which is the cornerstone of many other plans throughout the city, including the Austin Energy Resource, Generation, and Climate Protection Plan to 2035.

While acknowledging the often unseen and indirect costs of fossil fuel-based energy generation broadly is an important step in the right direction. Establishing the additional benefits of renewable energy and the value they can contribute to the Austin community can help policymakers and leaders in the City more aggressively pursue renewable energy, and achieve the goals set out in plans such as the 2035 Plan and the Austin Climate Equity Plan.

This paper seeks to focus directly on Austin and the Austin Energy Resource, Generation, and Climate Protection Plan to 2035, applying a co-benefits assessment tool developed by the Energy and Environmental Systems (EES) laboratory at Kyushu University, Japan, to quantify potential environmental, health and economic benefits of the three solar-related goals outlined above. This approach aims to offer greater insight into the often-unaccounted-for benefits associated with renewable energy development as an alternative to fossil fuels, and to ultimately help decision-makers be more informed when considering energy policies.

2. METHODS

2.1 Co-benefits Approach

As mentioned, the co-benefits approach can offer a more wholistic view on renewable energy policies by considering benefits beyond climate, such as impacts on human health and economies. Figure 1 depicts the general relationship between these co-benefits. Broadly, investing in renewable energy can 1) create climate benefits by reducing GHG emissions; 2) improve air quality by reducing GHG emissions, which can improve human health and result in positive economic impacts by reducing the income lost from illnesses or deaths exacerbated by air pollution; 3) create green jobs which come with positive economic impacts as workers will be earning income and contributing to the economy and 4) potentially generate surplus electricity which can be sold back to the grid, generating economic impacts.

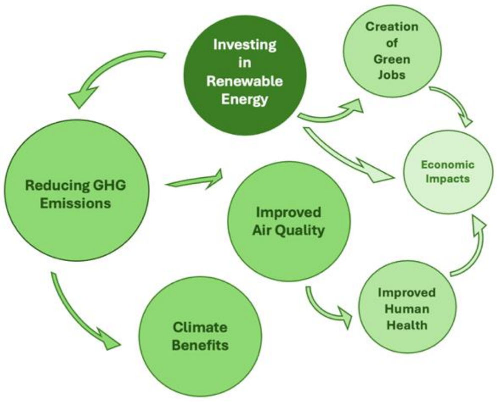

Fig. 1: Co-benefits considered in this approach.

The Co-benefits Tool developed by the EES lab quantifies such benefits by analyzing various energy scenarios and considering environmental, health, and economic co-benefits, along with a cost-benefit analysis that takes these co-benefits into account [6]. The tool can consider energy scenarios as "Grid-tied" or "Off-grid" microgrids that can meet demand-load requirements from a single household to large communities. Because of this, “off-grid” scenarios can be run, where we consider the energy scenario to be disconnected from the larger grid and, therefore, must be “self-sustaining.” In these off-grid scenarios, the electricity demand cannot be higher than the electricity supply, as the larger grid cannot supplement electricity to meet any additional demand. We can then determine the approximate number of units (Austin Energy customers) such a scenario can sustain. Moreover, battery storage must be included in an off-grid scenario, to ensure that electricity demand can be consistently met. Additionally, any surplus electricity generated in an off-grid scenario cannot be sold back to the grid. On the other hand, in grid-tied scenarios, any electricity demanded that surpasses what is supplied by the energy scenario can be imported from the grid. Here we can also determine the number of customers that an energy scenario can provide electricity to. Additionally, any surplus electricity generated from the energy scenario can be sold back to the grid.

Scenario Definition: This paper looks at these co-benefits for the three solar energy plans outlined in the Austin Energy Resource, Generation, and Climate Protection Plan to 2035. These three plans will have two scenarios each: grid-tied and off-grid. In total, six scenarios will be considered:

1. 350 MW Solar
   a. Grid-tied.
   b. Off-grid (with battery storage).
2. 500 MW Solar
   a. Grid-tied.
   b. Off-grid (with battery storage).
3. 700 MW Solar
   a. Grid-tied.
   b. Off-grid (with battery storage).

Energy Systems Analysis: The first step in this co-benefits approach is to consider the plans for renewable energy for the area, in this case, Austin, Texas’ solar plans. Here, we consider the installed capacity of the three scenarios outlined above, along with location and weather data for Austin to understand how much electricity could be supplied from these three solar energy scenarios. Solar cell technology is assumed to be monocrystalline, as it is the most efficient way to pursue solar development using this technology. The surface slope of the solar technology is also assumed to be the standard 30 degrees.

Here, we also consider the average per-capita hourly community-wide electrical load for a year, to understand how/if the energy supplied by these solar scenarios can meet the energy demand of the community, and if it cannot meet full community demand, we can get a sense of how many customers can be supplied by these solar scenarios. For off-grid scenarios, we can get a sense of how much battery storage would be needed to ensure electricity demand is consistently met during times when the solar electricity is not generated in sufficient quantities. We can also get a sense of how many customers this off-grid scenario would be able to sustain from solar energy and battery storage alone.

Considering these factors, we can gain insight into the monthly generation and consumption of electricity provided by these solar scenarios, monthly electricity supply mix (the proportion of energy supplied from the solar scenarios, and the amount supplied from the grid), and hourly average electricity supply-demand (to see how hourly energy generation/supply from various sources, namely solar and battery in this case, compares to hourly consumption/demand).

Environmental Co-benefits: Next, emission factors are considered. We consider the rate of CO_2, N_2O, CH_4, $PM_{2.5}$, CO, SO_2, and NO_x emissions from electricity generation from the grid. Since solar power does not produce emissions from energy generation, we can quantify the amount of emissions that are avoided since a portion of energy is now coming from solar, as defined in the scenarios, instead of from the grid. A reduction in these climate-forcing emissions has positive impacts on climate, as well as local air quality, especially in the case of PM2.5 which is particularly detrimental to human health.

Health/Economic Co-benefits: The current concentration of $PM_{2.5}$ (ug/m^3) in the region and the current $PM_{2.5}$ emissions (tons/year) from energy generation give an indication of the $PM_{2.5}$ exposure and how much $PM_{2.5}$ could be avoided from the increased renewable energy generation scenario. To better understand the health impacts of this exposure, DALYs data for six diseases that can result from or worsen due to $PM_{2.5}$ exposure are considered: Chronic Obstructive Pulmonary Disease (COPD), Ischemic Heart Disease (IHD), Cerebrovascular Disease (stroke), Lung Cancer (LC), Acute Lower Respiratory Infections (ALRI), Tuberculosis and Bronchus (TB). DALYs, or Disability-adjusted life years, are defined by the World Health Organization as follows: " One DALY represents the loss of the equivalent of one year of full health. DALYs for a disease or health condition are the sum of the years of life lost due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population" [7]. Considering the rate of these DALYs in a population, we can not only get a sense of the health impacts, but by also considering the population size and per capita GDP of Austin, we can also get a sense of the economic loss that is a result from the life years lost due these diseases which are exasperated by this $PM_{2.5}$ exposure.

On a less morbid note, here is also where we consider the economic contribution of increasing renewable energy in terms of green job creation and the resulting green economic impact. By considering the investment in the renewables sector, with the number of jobs in the solar PV sector, and the number of jobs indirectly created for each solar job, we can get a sense of how many solar-based green jobs are created for every Megawatt of solar capacity added. Therefore, considering Austin's three solar goals, we can estimate the amount of green jobs that additional solar capacity will create. Moreover, by also considering the wages in the solar sector, we can get a sense of how much these jobs will contribute to the overall economy in Austin.

Cost-Benefit Analysis: A common hesitation around investing in renewable energy is the cost associated with such investments. Here, we consider the typical capital and maintenance costs in USD$/kW for solar PV (and PV-plus-battery for off-grid scenarios). However, when considering the benefits of the avoided economic loss of illness resulting from fossil-fuel-based energy emissions and air pollution, along with the economic contribution of green jobs that the increased renewable capacity will bring, the costs of investing in renewables become more dramatically offset. Moreover, in grid-tied scenarios, where surplus energy generated from this additional solar capacity can be sold back to the grid, the profits from selling this energy can also be considered as a benefit in the cost-benefit analysis. Overall, when taking the value of these benefits into consideration, the amount of time it would take to pay back these investments in solar is much shorter.

2.2 Data Acquisition

Electrical Load Data: Yearly Electricity Load data was derived from the Electricity Reliability Council of Texas (ERCOT)'s, which operates Texas' electrical grid, Confidentiality Expired Adjusted Meter Load Reports [8] via historical report request for all operating days of 2023. ERCOT collects this load data in 15-minute intervals, so the hourly load was summed, and the average hourly load was then taken for every month. Only data for the Austin Energy Load Zone (LZ AEN) from these reports was considered, which was divided into the categories of "residential, commercial, and community" based on Austin Energy's 2023 annual reporting on the numbers of customers in each category and their respective annual electricity consumption [9].

Meteorological Data*:* Meteorological data for Austin's location and weather was collected from Solcast [10], where hourly dry bulb temperature, relative humidity, atmospheric station pressure, field global horizontal radiation (Wh/m^2), field direct normal radiation (Wh/m^2), field diffuse horizontal radiation, and field wind speed (m/s) was considered for the year 2023.

Emissions & Air Quality Data: Data on the emission factors of electricity generation was collected from the U.S. Environmental Protection Agency (EPA)'s eGrid 2022 summary tables [11] for the ERCOT subregion's total output emission rates (lb./MWh) for the pollutants of: CO_2, CH_4, N_2O, SO_2, and NOx. Emissions data for $PM_{2.5}$ (lb./MWh) was also collected from EPA's eGrid for the ERCOT subregion; however, EPA compiles $PM_{2.5}$ data separately and data from 2021 was the most recent available [12]. While this data is for ERCOT as a whole, any energy Austin imports from the grid would carry these emission factors. CO data was not available from the EPA's eGrid. However, EPA data on CO emissions from electrical generation via combustion facilities within Travis County (the county Austin is located within) was available in tons per year (2020 was the most recent data available) [13], which was divided by the yearly kWh Austin consumed from those facilities to achieve the emission rate.

$PM_{2.5}$ exposure is based on data for local $PM_{2.5}$ emissions (t/y) from energy generation and the current concentration of $PM_{2.5}$ in the area. Data for $PM_{2.5}$ emissions was collected from the EPA's COBRA tool's 2023 baseline $PM_{2.5}$ emission for Travis County's fuel combustion for electric utility [14]. Data for $PM_{2.5}$ concentration (ug/m^3) was available through Texas Commission on Environmental Quality (TCEQ)'s Air Quality Index (AQI) and Data Reports [15]. Yearly data

PM2.5 was collected and averaged for two air-quality monitoring sites: Austin North Hills Drive (CAMS 3) and Austin Webberville (CAMS 171). These sites were selected because they were two of three sites that monitor $PM_{2.5}$ in Austin. The third site was excluded because it is located on I-35, a major interstate highway, where $PM_{2.5}$ levels would likely not reflect those from energy generation but rather transportation.

Health Data: DALYs data was collected from the Institute for Health Metrics and Evaluation (IHME) for the State of Texas for six diseases: COPD, IHD, Stroke, Lung Cancer, Acute Lower Respiratory Infections, and TB. [16]

Green Economy Data: Data for the number of employees and annual average wages in the Solar Electric Power Generation (NAICS 221114) came from the U.S. Bureau of Labor Statistics (BLS)'s May 2023 National Industry-Specific Occupational Employment and Wage Estimates [17]. Annual average wages were divided by twelve to derive monthly average wages. The employees were further divided based on employment type (referred to as "occupation title" in BLS data) into the categories of "construction" and "operations." Additionally, employment multipliers from the Economic Policy Institute (EPI) for "direct, indirect, and induced" employment in the "Electric power generation, transmission, and distribution" sector (NAICS 221100) were considered [18]. Data on capital investment in the Electric power generation, transmission, and distribution" sector (NAICS 221100) came from the U.S. Bureau of Economic Analysis (BEA)'s Input-Output Accounts data using the Use Tables (Use of commodities by industry, before redefinition) for 2017 [19]. Since the most granular data available was for the entire electric power generation, transmission, and distribution sector, this number was divided based on the percentage of solar energy in the U.S. to find capital investment in the solar sector specifically.

Costs & Market Data: Data on capital investment and maintenance costs of solar (and solar with battery storage) came from the National Renewable Energy Laboratory (NREL)'s median estimation for 2020 capital costs (CAPEX) and 2021 maintenance costs (fixed O&M) of utility-scale PV in for grid-tied scenarios [20]. For off-grid scenarios, NREL's 2021 median estimation of CAPEX and O&M costs in $/kW for Utility-Scale PV-Plus-Battery was considered [21]. The current U.S. discount rate of 5.5% was also considered [22].

Data on the Electricity Purchase Price ($/kWh) was derived from ERCOT's Historical Real-Time Market (RTM) Settlement Price Points (SPPs) for the Austin Energy Load Zone (LZ AEN) for the year of 2023 [23]. These SPPs (recorded in 15-minute intervals) were averaged to achieve the electricity tariff.
The Electricity Selling Price ($/kWh) can be used as an energy feed-in tariff. Data on the mean feed-in tariff price for Solar PV in the U.S. was collected through the Organisation for Economic Co-operation and Development (OECD) for the year 2018, the most recent available [24]. However, it should also be noted that there are additional local and state policies in place that, if considered here, could further increase the selling price of electricity if it comes from renewable sources. These policies are typically created to promote renewable generation in line with state and local climate/environmental/energy goals. One such policy is the Renewable Energy Credit Program, administered by ERCOT, in which a facility that "relies exclusively on an energy source that is naturally regenerated such as solar," can earn tradable Renewable Energy Credits (RECs) [25]. In August of 2020, S&P Global reported the value of these Texas RECs to range from $1.20/MWh to $1.40/MWh. [26]

3. RESULTS

3.1 Scenario 1a: 350 MW Solar; Grid-tied

In Scenario 1a, we consider Austin's plan to reach 350MW of rooftop solar by 2027 in a grid-tied scenario. Here, we can see the avoided emissions, DALYs, and contribution to the green economy, as well as the value added by co-benefits in the cost-benefit analysis.

Energy System Analysis: Based on per-capita community demand, and the capacity of a 350 MW rooftop solar project, we can expect to supply approximately 30,678 Austin Energy customers with electricity generated from this project. This quantity of customers results in a yearly energy demand of 831,726 MWh, which nearly matches the 831,720.9MWh of annual energy supplied by this 350MW solar scenario. However, as seen in Figure 2, this capacity still does not fully meet the energy demand of these 30,678 customers, and electricity from the grid would be needed to supplement the electricity supply.
The reason electricity from the grid is required to supplement the supply from Solar Scenario 1a is because energy demand and energy supply from this solar scenario peak at different times throughout the day, as seen in Figure 3. Solar electricity supply for this scenario peaks around 12:00PM-5:00PM (12:00-17:00), however, electricity is demanded (average load) throughout the day, in hours outside12:00PM-5:00PM.

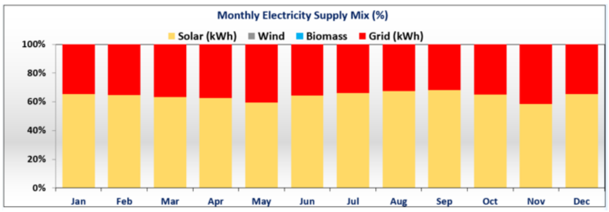

Fig. 2. Monthly Electricity Supply Mix for Scenario 1a: The percentage of energy supplied from the Solar Scenario 1a, and the amount supplied from the grid.

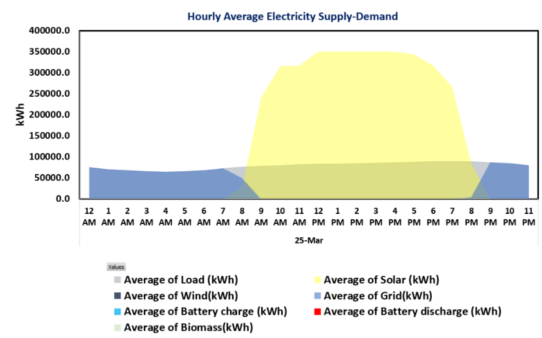

Fig. 3. Hourly Average Electricity Supply and Demand for Scenario 1a.

Environmental Co-benefits Analysis: By considering the emission factors from energy generation for the grid (ERCOT in this case), we can understand the emissions associated with importing all energy from the grid. So, increasing the amount of electricity that is generated from solar energy instead of being imported from the grid results in an amount of emissions avoided by making this switch to solar power. The emissions avoided based on Solar Scenario 1a are detailed in Table I.

Table 1. Scenario 1a Avoided Emissions

	Emissions Avoided
GHG	292,149.4 (t/y)
$PM_{2.5}$	15,882.7 (kg/y)
CO	135,228.4 (kg/y)
SO2	153,545.6 (kg/y)
NOx	176,566.0 (kg/y)

Health/Economic Co-benefits Analysis: Like with the environmental co-benefits, based on this scenario of 350MW Solar, we can understand how the human exposure to $PM_{2.5}$ that results from combustion-based energy production would decrease as a portion of that energy production is now replaced with solar. With less $PM_{2.5}$ exposure, we can expect a decrease in DALYs as outlined in Figure 4, which shows 1,577 DALYs averted, a $PM_{2.5}$ reduction of 15883 kg, GHG reduction of 292,149 tons, resulting in a cost saving of $100,650,000per year. Additionally, we can expect that this capacity of solar (350MW) can generate an estimated 2947green jobs, with an estimated economic impact of $2,676,000, as seen in Figure 5.

Cost Benefit Analysis. The combination of the savings and economic impact outlined above can be considered as benefits in the cost-benefit analysis of this 350MW rooftop solar project. Additionally, in a grid-tied scenario, the surplus energy produced by this project (which can be seen in Figure 3 around the hours of 9:00AM-7:00PM) can be sold back to the grid, further adding to the benefits.

If we consider the feed-in tariff rate of $0.004/kWh [24], we can expect a pay-back period of approximately eight years, compared to over thirty years without considering these co-benefits and feed-in tariff, as seen in Figure 6. However, if we consider the Renewable Energy Credit (REC) as the electricity selling price, the payback period decreases even more dramatically, to only two years, as seen in Figure 7.

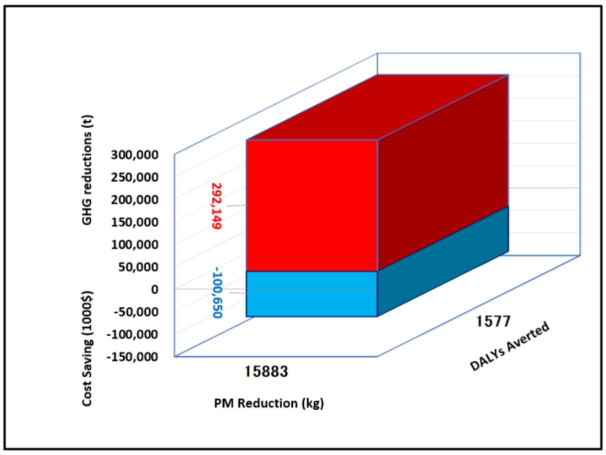

Fig. 4: $PM_{2.5}$ & GHG reduction, averted DALYs, and cost savings for Scenario 1a.

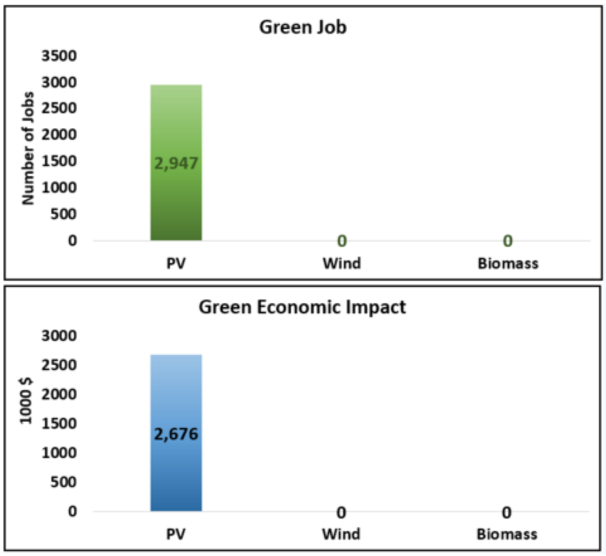

Fig. 5. Green Job and Economic Impact of Scenario 1a.

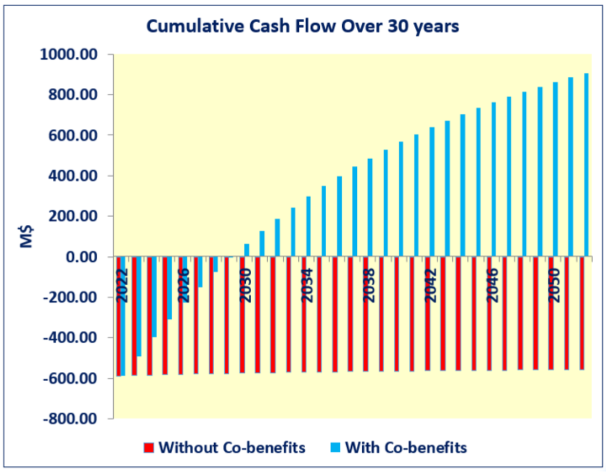

Fig. 6. Cumulative Cash Flow over 30 years for Scenario 1a (350MW Solar, grid-tied), considering a feed-in tariff of $0.004/kWh.

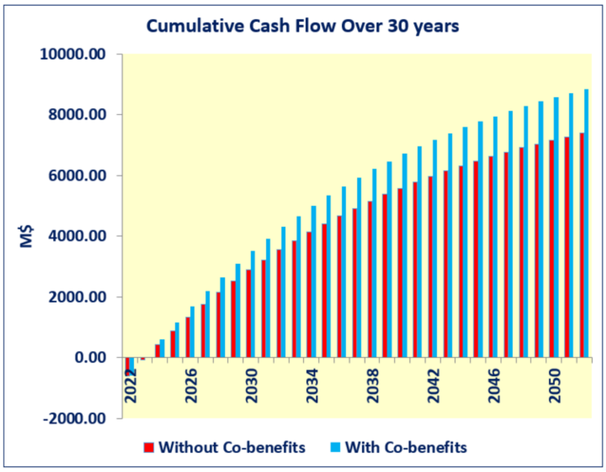

Fig. 7. Cumulative Cash Flow over 30 years for Scenario 1a (350MW Solar, grid-tied), considering a REC of \$1.20/kWh.

3.2 Scenario 1b: 350 MW Solar; Off-grid (with battery storage).

In Scenario 1b, we consider the 350MW rooftop solar project in combination with battery storage, as it is an off-grid scenario. As seen in the previous scenario (1a), solar electricity production peaks at a time that does not align with energy demand peaks; therefore, storage is needed to supply energy when solar generation is not sufficient to meet demand.

Energy System Analysis: In a system where the only energy supplied is from 350MW of solar, approximately 28,334 customers can be sustained from this electricity. A battery capacity of 1,750,565kWh would be needed to consistently meet demand. Figure 8 depicts the sources of electricity supplied by the hour.

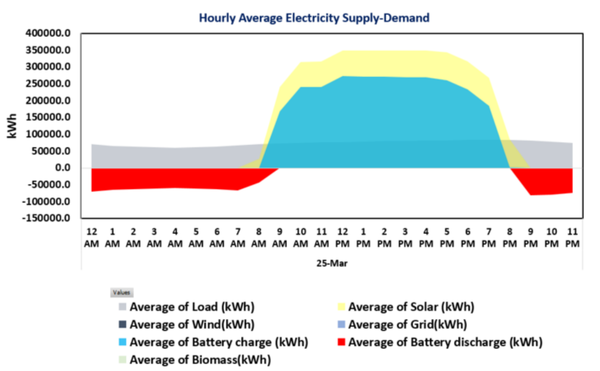

Fig. 8. Hourly Average Electricity Supply-Demand for Scenario 1b

Environmental Co-benefits Analysis: Since an amount energy is not being imported from the grid, emissions are also avoided in this scenario. However, since the system is off-grid and cannot support any more demand than it can supply, the amount of customers this system can support is smaller, and avoided emissions are lower than the grid-tied scenario. Avoided emissions are detailed in Table II.

Table 2. Scenario 1b Avoided Emissions

Emission Factor	Emissions Avoided
GHG	269,828.9 (t/y)
$PM_{2.5}$	14,699.3 (kg/y)
CO	124,896.9 (kg/y)
SO2	141,814.6 (kg/y)
NOx	163,076.2 (kg/y)

Health/Economic Co-benefits Analysis: For a 350MW Solar, off-grid system with battery storage, we can expect approximately a 269,829 ton reduction in GHG, a 14,669 kg reduction in $PM_{2.5}$, 1,455 averted DALYs, resulting in cost savings of \$92,872,000 per year, as displayed in Figure 9.

The green jobs and green economic impacts are derived in part based on the capacity of energy generation from various renewable sources. Since batteries store energy rather than generate it, battery storage capacity is not considered in the green job and green economic impact sections; rather the amount of green jobs and green economic impact are based on the solar capacity. As the solar capacity in this scenario is the same as the previous, grid-tied scenario (350MW), the green jobs and green economic impact are the same as the previous scenario, as seen in Figure 7.

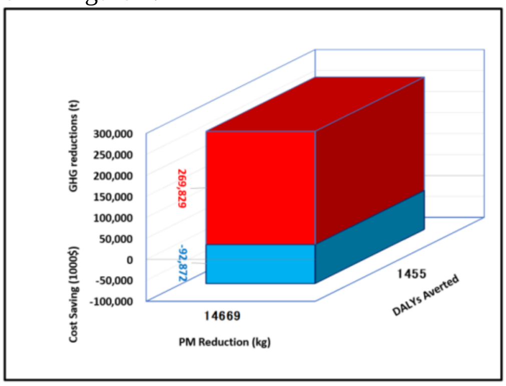

Fig. 9: $PM_{2.5}$ & GHG reduction, averted DALYs, and cost savings for Scenario 1b.

Cost Benefit Analysis: As shown in Figure 10, in this scenario, the payback period of investing in these renewable technologies is approximately twelve years, as opposed to over thirty years without considering the co-benefits.

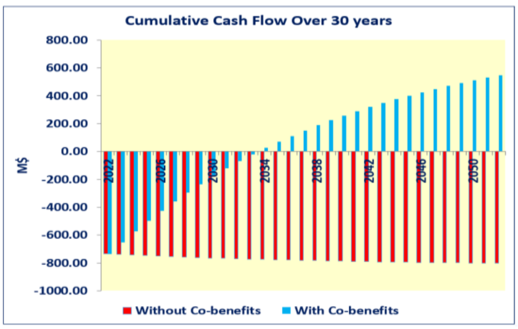

Fig. 10. Cumulative Cash Flow over 30 years for Scenario 1b (350MW Solar, off-grid with battery storage)

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3.3 Scenario 2a: 500 MW Solar; Grid-tied

In Scenario 2a, we consider Austin's plan to reach 500MW of rooftop solar by 2030. As in the previous scenarios, we can see the avoided emissions, DALYs, contribution to the green economy, and how these co-benefits, along with the ability to sell surplus energy back to the grid, will impact a cost-benefit analysis. With the capacity of a 500MW solar project, we can produce 1,188,172.7 MWh of electricity and expect to supply approximately 43,825 Austin Energy customers with the electricity generated from this project. However, like Scenario 1a, despite this near supply-and-demand match, this scenario does not fully meet energy demand, because of the difference in peak supply and demand times, and so the grid would need to supplement energy supply at times where solar supply does not meet demand.

For a 500 MW Solar scenario, we can expect a reduction in GHG of 417,356 tons, a 22,690 kg reduction in $PM_{2.5}$, approximately 2,104 DALYs averted, and cost saving of approximately $134,305,000 per year, as displayed in Figure 11. Additionally, with a 500MW Solar scenario, we can expect approximately 4,210 green jobs to be added, with an economic impact of $3,823,000. The payback period for this scenario is approximately eight years, and if we consider the REC to be the electricity selling price, the payback period is only about two years (compared to over thirty years without co-benefits).

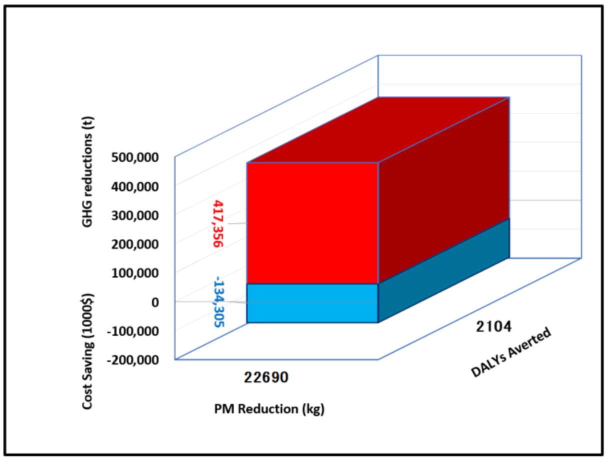

Figure 11. $PM_{2.5}$ & GHG reduction, averted DALYs, and cost savings for Scenario 2a.

3.4 Scenario 2b: 500 MW Solar; Off-grid (with battery storage):

In an off-grid scenario with 500MW solar, approximately 40,431 customers could be supported with additional battery storage of 2,497,956 kWh. We can expect a reduction in GHG of 385,030 tons, a $PM_{2.5}$ reduction of 20,932 kg, 2,077 DALYs averted, and a cost savings of $132,585,000 per year (See Figure 12), with a payback period (with co-benefits) of twelve years.

3.5 Scenario 3a: 700 MW Solar; Grid Tied:

With a capacity of 700 MW, this solar scenario would be able to supply 61,355 customers with a yearly energy supply of 1,663,441.7 MWh. For this scenario, we can expect a reduction in GHG of 584,299 tons, a 31,765 kg reduction in $PM_{2.5}$, approximately 2,966 DALYs averted, and cost savings of approximately $189,351,000 per year, as displayed in Figure 13. Additionally, with a 700MW solar scenario, we can expect to create 5,894 green jobs, with an economic impact of $5,352,000.

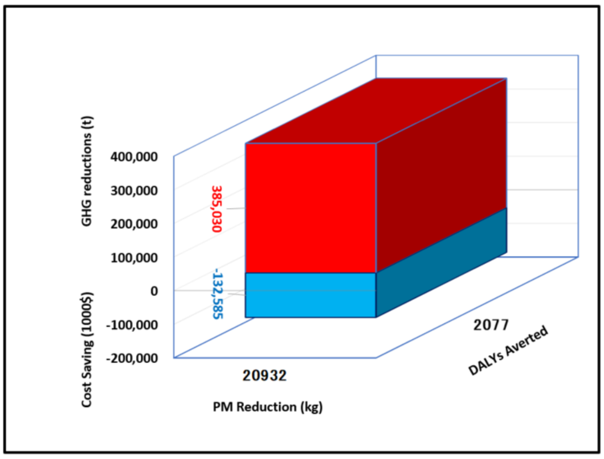

Figure 12. $PM_{2.5}$ & GHG reduction, averted DALYs, and cost savings for Scenario 2b.

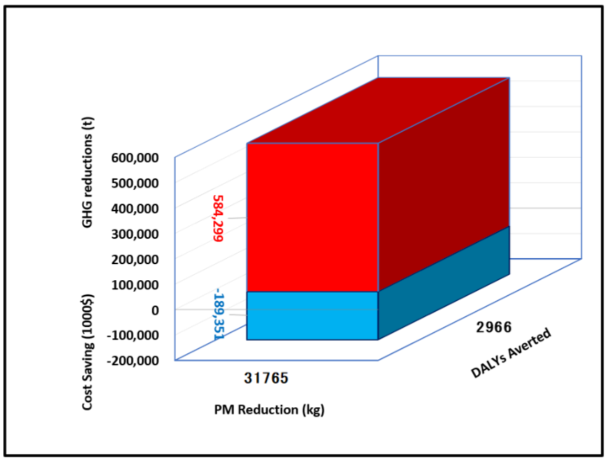

Figure 13. $PM_{2.5}$ & GHG reduction, averted DALYs, and cost savings for Scenario 3a.

As the last grid-tied scenario, we can consider surplus solar energy that is sold back to the grid in a cost-benefit analysis. Considering the co-benefits above, along with a feed-in tariff rate of $0.004/kWh, we can expect a payback period for this investment in solar of approximately eight years compared to the over-thirty-year payback period without these co-benefits. If the REC is considered the electricity selling price, the payback period is only approximately two years.

3.6 Scenario 3b: 700MW Solar; Off-grid (with battery storage):

In an off-grid system with 700MW Solar, approximately 56,490 customers can be supported with the addition of 3,490,133 kWh battery storage. The co-benefits assessment of this scenario is shown in Figure 14. We can expect a payback period (with co-benefits) of thirteen years.

4. DISCUSSION

4.1 Limitations

One significant challenge faced during the data acquisition process was that this co-benefits tool was developed primarily for Japan, and as a result, exact corresponding data from the U.S. was not always available. As a result, some data for the inputs of this tool are close estimates or comparable approximations rather than exact data. This is especially true in the case of green jobs and green economic impact, which were developed based on Japanese Input-Output (IO) tables, while U.S. IO tables are compiled very differently. Because of this, the results of this paper should be taken less as exact numbers that will result from these scenarios, but rather an approximation of the additional value these scenarios will have on the Austin community.

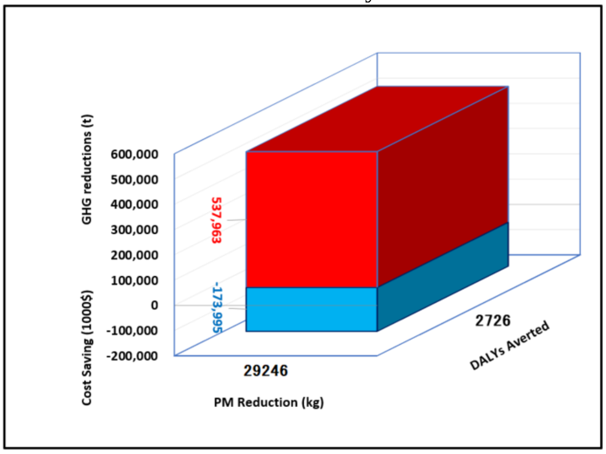

Figure 14. $PM_{2.5}$ & GHG reduction, averted DALYs, and cost savings for Scenario 3b.

4.2 Future Research

This paper focuses only on the solar plans outlined in the Austin Energy Resource, Generation and Climate Protection Plan to 2035 (2035 Plan) as reccomended by the EUC Working Group and the battery storage needed to sustain off-grid corresponding scenarios. However, the 2035 Plan also lays out *separate* goals for battery storage, with goals of adding 150 MW storage by 2027, 400 MW storage by 2030, and 500 MW storage by 2035. In future work, this tool may also be adapted and applied for the co-benefits analysis of battery storage and these plans. Additionally, the 2035 Plan sets goals for Austin Energy's renewable portfolio as a whole, with goals of 65% of its energy portfolio comprised of renewables by 2027, a 70% by 2030, and 80% by 2035. As seen in the cases of these three scenarios, the solar plans alone will not meet the total community energy demand. This tool can help suggest how much wind, biomass, or additional battery storage will be needed to meet the goal of net-zero emissions by 2040, as well as the value the co-benefits of these renewables could contribute to Austin.

4.3 Conclusions

As the city continues to face climate change and strives for an equitable climate future, it is increasingly important for Austin Energy and Austin as a whole to get a sense of the additional value solar and renewable energy can bring to the community. Understanding this value can help policymakers continue to push for much-needed changes to bring about net-zero community emissions by 2040. While this paper demonstrated the value of these solar plans, it also implies the losses, both monetarily and in human life, that Austin will face if renewables are not considered a priority. Austin, in many ways, cannot afford to delay a greener future.

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