APPENDIX H. Updated Memorandum from Tetra Tech to Paeahu Solar LLC; Subject: Heat Island Effect in Context to the Proposed Paeahu Solar Project, Maui County, Hawai‘

MEMO

To:	Paeahu Solar LLC c/o Julia Mancinelli, Director - Environment, Innergex Renewable Energy, Inc.
Cc:	Eddie Park, Director – Business Development, Innergex Renewables USA LLC
From:	Dr. Bob Pearson, Senior Project Manager, Tetra Tech
Date:	Original Issuance: Monday, December 24, 2018 Updated: Monday, July 20, 2020 Updated: Wednesday, August 31, 2022
Subject:	Heat Island Effect in Context to the Proposed Paeahu Solar Project, Maui County, Hawaii

Paeahu Solar, LLC (Paeahu Solar) proposes to construct and operate the Paeahu Solar Project (Project) on privately owned land near Wailea, on the Island of Maui, Hawai‘i. The Project will consist of a 15-megawatt solar photovoltaic system coupled with a 60-megawatt-hour battery energy storage system. The Project will be located approximately 0.6 miles east of Pi‘ilani Highway, on the western portion of tax map key 2-1-008:001, owned by Ulupalakua Ranch. The solar photovoltaic system will consist of a series of photovoltaic panels mounted on a fixed-tilt racking system, as well as related electrical equipment. The panels will be organized in rows within several solar array areas. Once mounted on the racking system, the highest point of the panels on level ground is expected to extend approximately 7.5 feet above the ground surface, with an average of 4 feet of ground clearance below the panels. The solar arrays and associated infrastructure would be sited within a 212-acre Project study area. Paeahu Solar anticipates that the total combined footprint of Project components will be approximately 150 acres (Project Area), of which the solar panels will cover approximately 50 acres. The Maui Meadows neighborhood is located downslope of the Project Area; the Project's closest solar arrays would be set back a minimum of 300 feet from the closest property line.

Solar energy is the conversion of sunlight into usable energy forms. The sun's rays transmit light energy, in the form of photons, which can be converted to electricity using certain materials that naturally release electrons when exposed to light. These materials are contained within the photovoltaic solar panels. Paeahu Solar plans to install conventional crystalline-silicone solar panels at the Project, which have the capability to convert 19 percent of the incoming sunlight to electricity. Another roughly 10 percent of the sunlight will be reflected from the transparent covers on the photovoltaic solar panels.[1] The remaining approximately 70 percent of the solar energy will be absorbed by the panels and converted to heat.

[1] It is possible this reflected light could produce glare at specific receptor locations at certain times of the day and year under certain atmospheric conditions. Paeahu Solar has conducted a glare analysis to identify these areas. Using this information, Paeahu Solar will site the panels to minimize glare impacts.

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Some studies have observed the creation of a "heat island effect" over a large utility-scale solar project (Barron-Gafford et al. 2016). Pono Power Coalition has expressed concern regarding the potential for the Project to induce a heat island effect that would raise the ambient air temperatures around the solar facility by 5 to 7 degrees. A discussion of the specific conditions at the Project in relation to potential heat island effect is provided below.

1. Definition of Heat Island Effect

The University Corporation for Atmospheric Research (UCAR), based in Boulder, Colorado describes formation of heat islands as:

> Heat islands form as vegetation is replaced by asphalt and concrete for roads, buildings, and other structures necessary to accommodate growing populations (UCAR 2011).

By this definition the urbanized area of Wailea-Makena-Kihei, including the Maui Meadows subdivision, forms a heat island effect along the southwest coastline of Maui. All urbanized areas form a heat island due to the replacement of natural vegetation with asphalt and concrete for roads, buildings, and other structures. The Maui Meadows subdivision itself causes a heat island effect. This is because the Maui Meadows subdivision roughly covers over 160 acres in non-vegetated material[2] such as buildings/roof tops, streets, pavement, etc. which is more than three times the size of the Project's total solar array area of 50 acres. Also, the hardscaped areas of the subdivision have a higher thermal mass and resulting heat storage capacity that will retain heat far into the night compared to the thin solar panels at the Project site.

Furthermore, the existing heat island presently formed by the 6.4-square-mile developed areas of Wailea-Makena-Kihei, including Maui Meadows, is eighty times the 50-acre area of the Project's solar panel area. Also, the meteorological patterns that currently occur in the Wailea area would interact with the Project solar panels to reduce any heating effect. For further explanation on the way the meteorological patterns influence the microclimate in and near the Project, please see Section 2 below.

2. Meteorological Patterns in the Wailea Area

The meteorological patterns in the Wailea Area are subject to the formation of sea breezes due to the proximity of the Pacific Ocean and its ability to absorb and store energy from the sun (NWS 2018). When the sun is shining, the Project's solar panels and the surrounding hillside will heat up and warm the air above, decreasing the air's density and creating a weak low-pressure area called a thermal low (see Figure 1, label #1). As the air above the panels will be warmer than the surrounding air, a chimney effect will occur (see Figure 1, label #3), and the warm air near the panels will rise into the atmosphere until it cools enough to reach the temperature of the surrounding ambient air (NWS 2018). By cooling, the density of the air increases again forming a small area of high pressure (see Figure 1, label #4). This

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[2] The Maui Meadows subdivision covers an approximately 410-acre area. Based on aerial photo interpretation, Tetra Tech assumes 40 percent of the subdivision is covered by non-vegetative material (e.g., buildings, streets, hardscapes).

typically occurs from 3,000 to 5,000 feet in elevation; at this level, the air pressure and density, being greater than the air at the same elevation over the water, causes the air to flow back over the water (see Figure 1, label #5). Once over water again, the air cools, increases in density and sinks toward the ocean surface (see Figure 1, label #6). This enhances high pressure near the ocean's surface (see Figure 1 label #7) and the cooler air over the ocean (to the west of the Wailea area) will replace the warm air that rises from the land surface during the day and will flow onshore toward the Project (see Figure 1, label #2) and up the surrounding hillside (NWS 2018).

This chimney effect over the warmer land surface occurs naturally in the existing conditions of the Project Area. This situation is typical during the day in ocean beach environments, where cooler ocean air blows onshore from the water to replace the rising air over the warmer land surface (NWS 2018). Due to these cooling onshore breezes from the ocean, daytime temperatures in Maui Meadows would not change due to the construction and operation of the Project because Maui Meadows is located upwind (i.e., the direction the wind is coming from) of the Project.

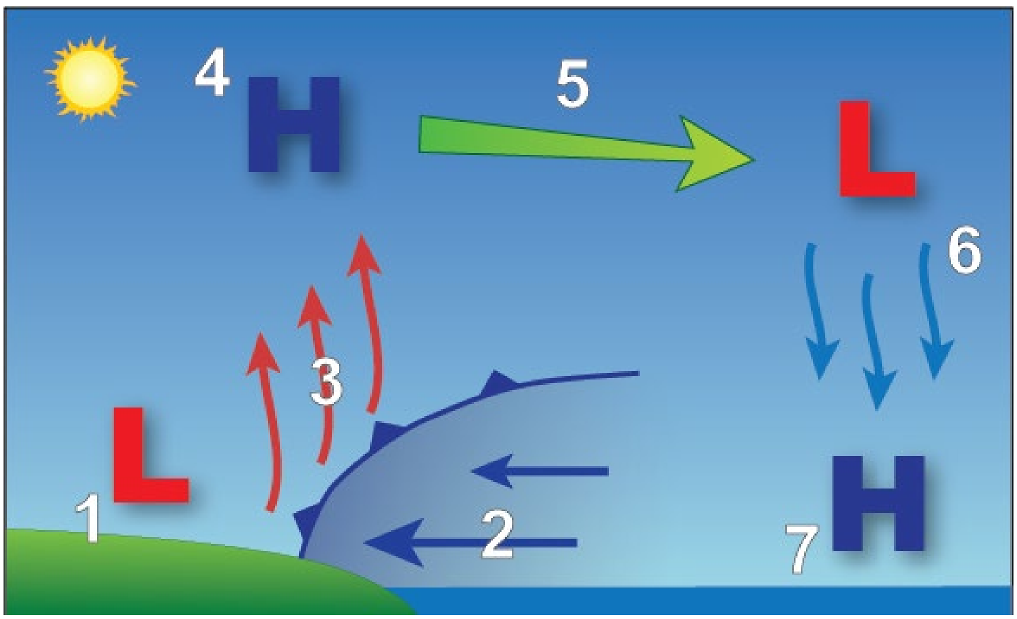

Figure 1. Daytime Air Movement in a Coastal Region (NWS 2018)

In the evening, a similar but opposite effect can result in the formation of land breezes. During and after sundown, the solar panels and the soil surface will cool to the temperature of the surrounding air. The air over the land surface will cool and will become denser forming a small area of high pressure (Figure 2, label #1). When the land surface is cooler than the ocean water surface, the cool, dense air will flow downhill to the beach and out over the water (Figure 2, label #2). The ocean water will create a chimney effect as the ocean water will warm the air near the water surface, thus decreasing the air's density, and cause the warmed air to rise into the cooler air above (Figure 2, label #3). The rising air forms a weak low-pressure area above the ocean surface (Figure 2, label #4) and a higher pressure area where the warmed air accumulates (Figure 2, label #5), typically occurring from 3,000 to 5,000 feet in elevation. At this elevation the air pressure and density, being greater than the air at the same elevation over the land, causes the air to flow back toward land from high pressure to low pressure (Figure 2, label #6). Once back over land, the air cools, increases in density and then sinks causing an increase in density and high pressure above ground (Figure 2, labels #7 and #1). Gravity pulls the dense air offshore again completing the circulation. This offshore flowing wind during the night is a natural occurrence on beaches around the world.

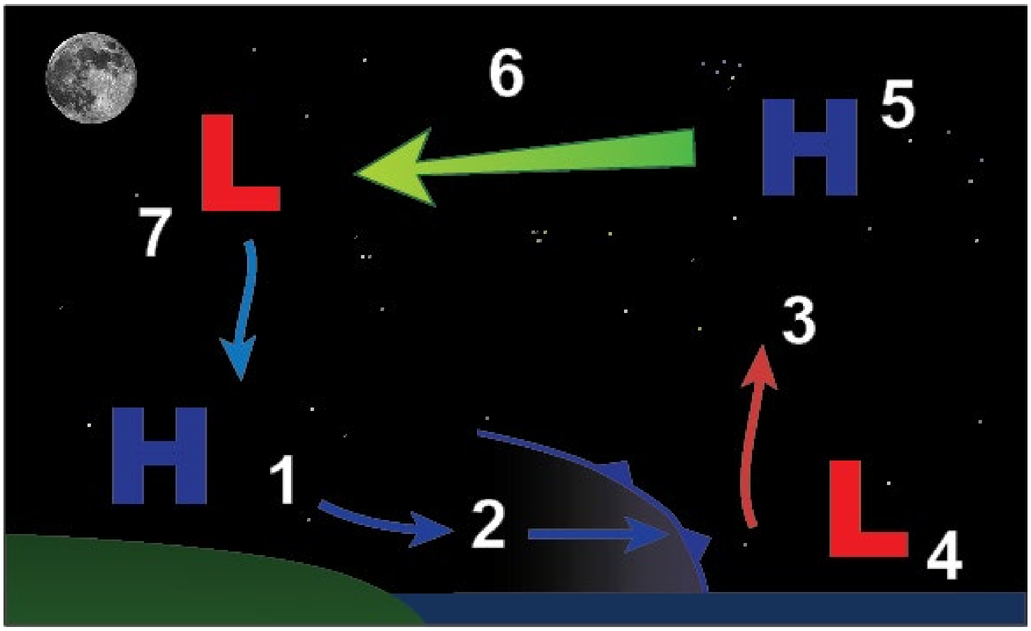

Figure 2. Nighttime Air Movement in a Coastal Region (NWS 2018)

During the day the ground beneath the solar panels will be shaded keeping the soil surface cooler than if the sun was shining directly on the soil. The cool onshore winds from the Pacific Ocean during the day and the cool downslope winds from Mount Haleakala at night will keep the soil surface beneath the panels about the same temperature as the ambient air.

It is possible that the daytime heating of the Project panels could slightly warm the soil beneath the panels by reradiating the heat from the panels to the soil surface below. However, this radiative heating effect will be small and will be offset by the cooling effect of the daytime upslope and nighttime downslope winds. The area beneath the panels would be relatively small (50 acres or less) and the Project is situated on the west-facing slope of Mount Haleakala, which climbs to an elevation of over 8,000 feet on the ridge east of the Kula Highway and is approximately 35 square miles. Due to the Project's solar array area being a fraction (less than 0.3%) of the area of the west slope of Mount Haleakala, the nighttime downslope winds that naturally occur in this area (see Figure 2, labels #1 and #2) would mix with and cool any remnant warm air beneath the solar panels.

Thus, even if there was a small heat island effect at the area immediately surrounding the solar panels, the upslope and downslope winds that naturally occur on the southwestern side of Maui (off the west-facing slopes of Mount Haleakala) would overwhelm any small heat island associated with the solar panels. This would result in cool air crossing the Maui Meadows area both in the daytime and in evening, as it does now. The area of the Project's solar panels is simply too small in relation to the area of the western slope of Mount Haleakala to have a significant impact on the natural upslope and downslope air movement in the Wailea area.

3. Response to Studies Cited by Pono Power Coalition

The study conducted by Barron-Gafford et al. (2016) compared temperature patterns measured at a solar farm in the Tucson, Arizona area, at an undeveloped natural desert area near the solar farm and at a nearby asphalt parking lot. The study observed that the temperature over the solar panels during the day is about the same as over the nearby desert. However, the study also found that the land beneath the solar panels was heated by the panels during the day and retained heat and stayed warmer than the natural (undeveloped) desert at night. This study was done within the University of Arizona Science and Technology Park Solar Zone in Tucson, Arizona. The findings from this study are specific to a solar facility constructed in the Tucson desert, where the ground under and adjacent to the solar panels is flat, devoid of vegetation, consisted of a light-colored soil, and was nowhere near a major surface waterbody.

The Tucson solar site differs from the proposed Project site in several ways resulting in entirely different microclimates. First, the entire Project Area will not be mass graded and will have vegetation within the solar array blocks and outside the location of other Project infrastructure. Therefore, much of the natural heat gain and storage characteristics of the ground within the Project Area will be preserved, which would be similar to the natural conditions outside of the Project Area.

Second, the Project is located on the sloped side of Mount Haleakala near the Pacific Ocean, resulting in natural offshore and onshore winds as described above (Section 2). The Tucson solar site is flat and located in a broad desert valley with no slope or surface waterbodies nearby. Therefore, the flat Tucson desert has no terrain induced upslope and downslope wind patterns to move warmed air away from the project site as happens in Wailea. The Project solar array area will comprise a relatively small area (less than 0.3%) of the west facing slope of Mount Haleakala. Even if the solar panels warm the underlying soil to a temperature higher than the natural ground (i.e., ground with no panels) during the day, and the assumed warmer soils release the heat during and after sunset, any warm air released by the soils below the panels would be cooled by the naturally occurring offshore winds. The volume of cool air flowing towards the ocean from the west facing slopes of Mount Haleakala will overwhelm any solar panel-caused heat released in the evening as the ground cools.

Binder (2016) discusses the Barron-Gafford et al. (2016) paper and states:

> The result demonstrates that there are potential heat costs to generating green power although the added heat dissipates quickly and can't be measured 100 feet away from the power plants. Considering the external costs of solar power, the discovery of this heat island effect may affect future decisions on when and where to convert natural ecosystems into large-scale solar facilities (Binder 2016).

In other words, the heat island effect observed and reported in the Baron-Gafford et al. (2016) paper is localized to the immediate solar facility itself and will dissipate within 100 feet. Although the phenomena observed in the Baron-Gafford et al. paper is not applicable to the Project, as the local microclimate and soil substrate is different, even if we assumed the heat island effect reported in the Baron-Gafford et al. paper were applicable to the Project Area, the heat island effect would dissipate within 100 feet. Since the Project solar arrays will be sited more than 300 feet away from the closest Maui Meadows parcel boundaries, any effect of a heat island from the solar farm will dissipate well away from the homes in Maui Meadows.

Another recent study conducted by Li et al. (2018) was recently referenced in a Los Angeles Times article (Kaplan 2018) titled "Wind and solar farms can make their own weather, including extra rain over the Sahara." The Li et al (2018) used a climate model to show that large-scale installations of wind and solar farms covering the Sahara Desert could lead to local temperature and precipitation increase. However, the study also states that wind and solar farm impacts are dependent on the specific location and spatial distribution and that assessment of impacts from smaller scale wind and solar farms at specific locations would require further study. The area of the Sahara Desert is 11,250,000 times the size of the Project. Additionally, the study was done in context to the desert environment, not a seashore environment. Therefore, the findings from the Li et al. (2018) study are not applicable to or representative of the Project.

4. Conclusion

The construction and operation of the Project will not significantly change the natural diurnal flow of air back and forth across Maui Meadows. Even if the solar panels slightly warm the underlying soil beneath the solar panels more than the natural ground during the day, this radiative heating effect will be small and will be offset by the cooling effect of the daytime upslope and nighttime downslope winds, which would overwhelm any small heat island beneath the solar panels. This would result in cool air crossing the Maui Meadows area both in the daytime and in evening, as it does now. The area of the Project is simply too small (less than 0.3%) in relation to the area of the western slope of Mount Haleakala to have a significant impact on the natural upslope and downslope air movement in the Wailea area. Therefore, the Project will not create a significant heat island affect that would impact the existing heat island microclimate of the Maui Meadows neighborhood.

5. References

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