Taylor & Francis
Taylor & Francis Group

Israel Journal of Ecology & Evolution

ISSN: 1565-9801 (Print) 2224-4662 (Online) Journal homepage: http://www.tandfonline.com/loi/tiee20

Integration of photovoltaic panels and green roofs: review and predictions of effects on electricity production and plant communities

Bracha Y. Schindler, Lior Blank, Shay Levy, Gyongyver Kadas, David Pearlmutter & Leon Blaustein

To cite this article: Bracha Y. Schindler, Lior Blank, Shay Levy, Gyongyver Kadas, David Pearlmutter & Leon Blaustein (2016) Integration of photovoltaic panels and green roofs: review and predictions of effects on electricity production and plant communities, Israel Journal of Ecology & Evolution, 62:1-2, 68-73, DOI: 10.1080/15659801.2015.1048617

To link to this article: http://dx.doi.org/10.1080/15659801.2015.1048617

Israel Journal of Ecology & Evolution, 2016
Vol. 62, Nos. 1–2, 68–73, http://dx.doi.org/10.1080/15659801.2015.1048617

Integration of photovoltaic panels and green roofs: review and predictions of effects on electricity production and plant communities

Bracha Y. Schindler[a]*, Lior Blank[b], Shay Levy [a], Gyongyver Kadas[c], David Pearlmutter[d] and Leon Blaustein[a]

[a]Department of Evolutionary and Environmental Biology, Kadas Green Roofs Ecology Center, Institute of Evolution and, University of Haifa, Haifa, Israel; [b]Department of Plant Pathology and Weed Research, ARO, The Volcani Center, Bet Dagan, Israel; [c]University of East London, TURAS Project, London, UK; [d]Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede Boker Campus, Israel

(*Received 7 October 2014; accepted 2 May 2015*)

The integration of photovoltaic (PV) panels and green roofs has the potential to improve panel efficiency to produce electricity and enhance green roof species diversity and productivity. In this review, we provide an overview of research on the effects of green roofs on PV panel electricity production, and predict the expected effects of the PV panel on green roof plant communities. Previous studies suggest that PV panels are more efficient above a green roof than above several types of conventional roofs due to the cooling effect of green roofs on the temperature-sensitive PV cells. Some ecological studies on shade suggest that shade imposed by panels may enhance the biotic productivity of green roofs. Shade is often shown to be important for seedling survival, particularly in arid environments – so the effect of shade on plants may depend on climate and irrigation. Previous studies also suggest that shade variations over the roof area may enhance plant diversity, as such heterogeneity creates niches of light and moisture levels that are appropriate for a diversity of plants. These positive effects on plant diversity may lead to increased arthropod diversity as well. Additional replicated studies are needed to test the reciprocal effects of green roofs and PV, as past studies lacked replication. Future directions for research that could guide the design of green roof–PV integration include the effects of irrigation, plant diversity, and green area-to-panel ratio on the roof.

Keywords: biodiversity; living roof; nurse object; solar panel; solar radiation; vegetated roof

Introduction

Both green roofs and photovoltaic (PV) panels provide environmental benefits; PV panels provide a renewable source of energy with low carbon emissions (Myhrvold & Caldeira 2012), and green roofs can create more resilient cities (Collier et al. 2013). Resilient cities are ones that are able to tolerate environmental changes without requiring complete reorganization (Collier et al. 2013), and green roofs can improve a city's resilience by, for example, mitigating the urban heat island effect, reducing the use of fossil fuel-derived energy for moderating the indoor climate of buildings, mediating stormwater runoff, and providing habitat for urban wildlife (Getter & Rowe 2006). These two technologies would appear to compete for space on roofs, but a growing number of studies suggest that integrating PV panels with green roofs provides benefits to panel performance (Table 1). Not only may green roofs improve the electrical output of PV panels (Köhler et al. 2007; Chemisana & Lamnatou 2014), but as we will argue here, the presence of PV panel arrays – which typically cover just a fraction of the roof area – may increase the biomass and diversity of the vegetation on green roofs in large part by providing a greater heterogeneity in solar radiation and soil moisture (see also Vasl and Heim 2016). This in turn can enhance green roofs' functions, including cooling effects and rainwater retention (Lundholm et al. 2010; Cook-Patton & Bauerle 2012), and potentially enhance arthropod diversity (Siemann 1998). We will support this hypothesis with preliminary studies of the effects of PV panels on green roofs and the effects of shade on green roofs. While the effects of green roofs on PV panel efficiency have been reviewed (Lamnatou & Chemisana 2015), there are the gaps in research on this aspect of the interaction between PV panels and green roofs. In addition, this review presents evidence for effects of PV panels on green roofs, an effect that has not been considered in depth in previous studies.

Effects of green roofs on photovoltaic panel output

PV panels become less efficient in converting solar radiation to electricity as their surface becomes warmer. This drop in the conversion efficiency occurs at a roughly linear rate of 0.025% per degree Celsius at ambient temperatures over 28 °C, where a PV module on a tile roof reaches 38 °C (Ubertini & Desideri 2003). In full sunlight, the PV conversion efficiency can be improved by 15% by wetting the panel with water, and thus cooling its surface by evaporation (Meral & Dinçer 2011). In addition, the accumulation of particles on the PV collector surface also degrades the panel efficiency, and while green roofs produce some particle pollution from pollen and substrate erosion, the net effect of green roofs is generally a reduction in the local particle accumulation (Tan & Sia 2005;

---

*Corresponding author. Email: bschindl@campus.haifa.ac.il

Table 1. Studies on the effects of green roof on PV efficiency.

Type of comparison	Location	Type of study	Change in efficiency with green roof	Source
Green roof vs. gravel	Spain	Empirical	1%−3%	Chemisana and Lamnatou (2014)
Green vs. concrete	Hong Kong	Model	8%	Hui and Chan (2011)
Green vs. bitumen	Berlin, Germany	Empirical	1%−10%	Köhler et al. (2007)
Moss vs. black	Pittsburgh, PA, US	Empirical	0.5%−(−2)%	Nagengast et al. (2013)
	Pittsburgh, PA, US	Model	−0.5%	
	San Diego, CA, US		0.7%	
	Huntsville, AL, US		0.6%	
	Phoenix, AZ, US		1.3%	
Green vs. gravel	NYC, US	Empirical and model	2%	Perez et al. (2012)
Green vs. black	Various US regions	Model	0.6%	Witmer (2010)
Green vs. white	Various US regions	Model	0.1%	Witmer (2010)

Speak et al. 2012). However, if the roof undergoes a drought, the plant dieback could produce particulate matter that may increase the net particulate pollution on the roof.

Green roofs tend to be cooler than conventional roofs due to evapotranspiration from the planted surface, with the extent of temperature depression varying according to the surface albedo and other physical properties of the two roofs (Pearlmutter & Rosenfeld 2008). The reduction in the emitted long-wave radiation as well as in the near-surface air temperature is expected to keep PV panels cooler and thus operating more efficiently (Scherba et al. 2011, Figure 1).

In a Web of Science search through January 2015 [using (“green roof*” or “living roof*”) and PV], we found no experiments with replicated plots to test this hypothesis, but mathematical models and studies comparing solar panels on green roofs and gravel or black roofs suggest that this is the case, particularly in the summer and in warm climates. Lamnatou and Chemisana (2015) provide a more in-depth review of this aspect of the synergy of PV panels with green roofs, so we only briefly summarize evidence for the effects of green roofs on panel efficiency here. An empirical study in Spain measured a 1%−3% increase in PV electricity production for a panel above a green roof plot compared to a panel above a gravel plot, with the magnitude of improvement in efficiency depending on the plant species used (Chemisana & Lamnatou 2014). In another study in Germany, PV panels above a green roof produced 7% more electricity than panels above a bitumen roof, but an accurate comparison was not possible in this case because the panels on the two roofs were of different design (Köhler et al. 2007). Chemisana and Lamnatou (2014) noted that PV panel efficiency improved over a green roof, in part, because the albedo of plants was higher than that of the gravel, resulting in a higher incidence of diffuse irradiance on the tilted panel’s collecting surface at low sun angles. The studies mentioned above provide useful evidence in support of green roofs elevating the electrical production by PV panels, but because they were done on a single roof without replication of treatments, stronger inference can only be made after empirical experiments with true replication are performed.

Several other studies have used mathematical models to compare the performance of PV panels installed on conventional and green roofs. In a study in New York, temperatures were measured on and underneath a simulated panel, above a gravel roof and a green roof, and a 2% improvement in the electricity production was predicted based on the cooling effect of the green roof (Perez et al. 2012). A weakness of the Perez et al. (2012) model is that it is based on parameters estimated from very limited field data in one location on small experimental modules. If larger modules were used, it would have reduced the possibility that the regular roof outside the border of

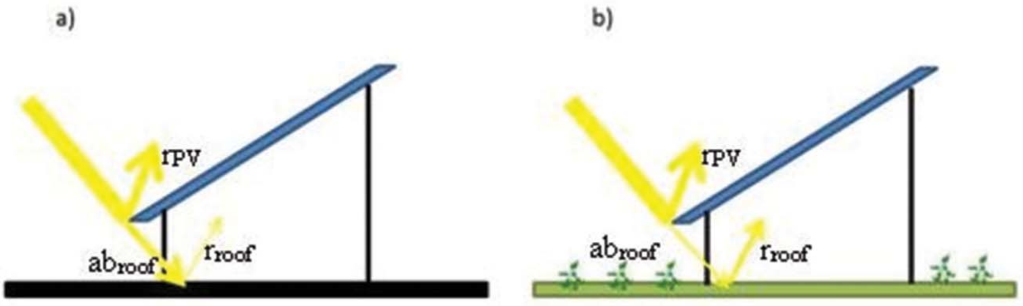

Figure 1. Illustration of absorptance (ab) and reflectance (r) of light from a conventional (a) and green (b) roof with PV panels. A green roof transforms less absorbed radiation into sensible heat and therefore remains cooler. Green and conventional roof absorptance values based on Saiz et al. (2006).

the module contributed to the temperatures below the PV panels. Another model predicted much smaller effects: a 0.1%–0.6% increase in power production by solar panels on green roofs compared to white and black roofs in various climates across the United States, with the greatest efficiency improvements occurring in the summer and in Mediterranean or desert climates (Witmer 2010). Witmer (2010) argued that a green roof would produce a greater cooling effect than a white roof over the years, as a white roof gets covered with dust and its albedo declines, while the albedo of the vegetation remains relatively constant over the years, as foliage is replaced, and it provides additional cooling through evapotranspiration. When considering both the added electricity production by the cooled PV panels on a green roof, and the reduced electricity consumption for air conditioning due to the cooling effect of the green roof, an 8% improvement in the net electricity demand is predicted for a building with a green roof compared to a concrete roof, based on the observed data in Hong Kong (Hui & Chan 2011). Based on models comparing the electricity production in San Diego, CA; Huntsville, AL; and Phoenix, AZ, the improvement in PV panel efficiency due to green roofs' effects is largely dependent on the climate, and areas that do not often experience ambient temperatures over 25 °C will not show much improvement in electricity production (Nagengast et al. 2013).

Effects of photovoltaic panels on green roofs

Herbaceous species compete for water, nutrients, and light (Grime 1977). Objects that block the sunlight will affect the soil moisture, soil temperature and radiation. Moreover, the PV-induced shade should cause greater heterogeneity in these physical factors (Figure 2). All these should affect species assemblages and the community structure in a given area. This can happen at a very small scale in a harsh environment, such as a dry Mediterranean climate. Therefore, the shade imposed by PV panels can have an effect on a green roof's plant community. Predictions of how the physical presence of PV panels affect the plant and animal community structure can be formulated based on how canopy affects understory communities.

Research on nurse plants, adult plants which provide shelter to seedlings (Callaway 1995) can provide some insight on the effects that PV panels may have on green roof plants. On the other hand, there are differences in the type of shade provided by nurse plants and objects, and they may have different types of effects on plants, so studies of green roof-integrated photovoltaic panels (GRIPV) have the potential to provide useful information on the effects of abiotic shade on plant communities.

Positive interactions between plant species are most important in harsh environments (Bertness & Callaway 1994), where the interactions make the environment less harsh, and in areas with high disturbance, where a positive relationship between densities of two species is possible (Brooker & Callaghan 1998). Extensive green roofs are harsh environments because they typically have a shallow substrate with a low availability of water and nutrients, and they are often exposed to high wind speeds – so positive interactions between PV panels and plants would be expected to be important in this environment. Moreover, PV panels, compared to nurse plants, would tend to provide more positive than negative effects to the affected species, as the panels do not compete for resources.

PV panels may enhance soil moisture by providing shade, and the dew collected on the panels would drip in concentrated areas surrounding the panel, increasing moisture heterogeneity, and creating microhabitats suitable for a diversity of plants. The PV panels would also provide shelter from wind, potentially enhancing plant growth. Sheltering by the panels may also prevent the wind dispersal of annual seeds from the roof, encouraging the maintenance of annual plant populations on a roof from year to year. The ability of PV panels to capture seeds would depend on the placement and size of the PV frame, the angle of the panels, and height of the panels above the substrate.

The PV array's design also affects the pattern of shadows cast, but in general, the shade produced by panels will be unlike the shade produced by shrubs or shade cloth. Trees and shrubs produce the patchy shade (Breshears & Ludwig 2010). The shade variability and the location throughout the day depend on the canopy shape (Blank & Carmel 2012) and the height and the density in woodlands (Breshears & Ludwig 2010). Unlike trees and shrubs, typical PV panels would create 100% interception of the direct solar radiation, but depending on the size of the array, shade on a particular plant might last for only a few hours throughout the day. Complete shade for a portion of the day is likely to have different effects from the partial shade experienced by understory plants

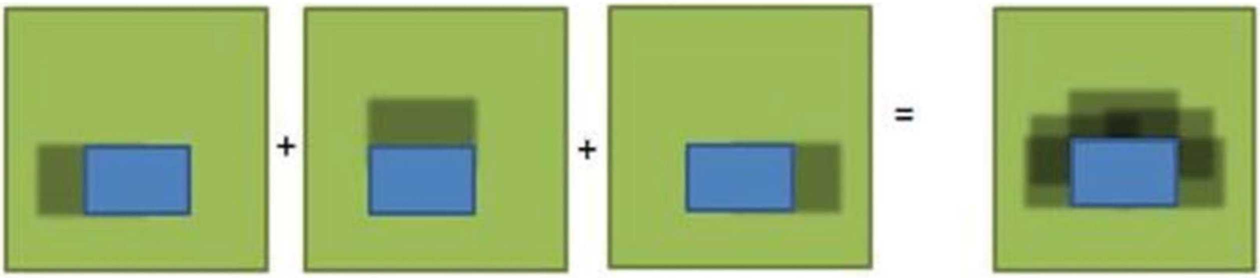

Figure 2. Illustration of the shade from photovoltaic panels in different locations on the roof throughout the day (three boxes on left) will create a heterogeneous shade environment with different durations of shading on different areas of the roof (box on right).

throughout the day. The GRIPV system is expected to be spatially heterogeneous in shade cover; some parts of the roof will receive shade from the nearest panel while others will also receive shade from neighboring panels, and other parts will not receive shade at all (Figure 2). The result will be a highly heterogeneous environment with multiple niches, in a relatively small area, that will support a large number of plant species.

This type of heterogeneity on the roof, created by a mixture of PV-shaded and non-shaded areas (Figure 2), can also allow competing species to coexist, partly because plants do not reach a size that allows them to compete, as they are limited by light (Valladares & Niinemets 2008), but also because different species perform best at different levels of light (Callaway 1994; Zavala et al. 2000). Since shade and its effects benefit some species, but are detrimental to other species, a heterogeneous environment with different levels of shade, as would be found on a green roof partially shaded by PV panels, would be expected to produce a diverse plant community, relative to a homogenously sunlit roof.

Studies of non-PV shade on green roofs

It is useful to examine the effects of shade on green roofs, separately from other habitats, because the shallow substrate of green roofs undergoes dramatic changes in moisture, which may interact with the shade to affect plants. There have been few studies of shade on green roofs. These studies suggest that shade, by affecting abiotic conditions on green roofs, in turn affects germination, growth rates of the plants, and the plant composition. Some of the species most commonly used on green roofs germinate at specific light levels (Benvenuti & Bacci 2010), and some green roof species produce greater cover in shaded areas, while others produce more cover in non-shaded areas (Getter et al. 2009). Over time, areas with different levels of light and reflectance can achieve different plant compositions (Dewey et al. 2004).

Studies comparing abiotic characteristics between the shaded and non-shaded areas of green roofs found contrasting results. One study found that sunny plots captured more water when watered, indicating that the substrate moisture was initially lower in these plots (MacIvor & Lundholm 2011), while another study found that the substrate moisture was higher in sunny plots (Getter et al. 2009). Although sunny plots were drier in the study of MacIvor & Lundholm (2011), they were also cooler than shaded plots. Since this study was not specifically designed to measure the effects of shade, and plots were in a gradient of shaded to sunny, it is possible that other factors contributed to this trend (MacIvor & Lundholm 2011). The substrate moisture is not affected by abiotic conditions alone. Favorable conditions under PV panels can create a negative feedback loop, where high substrate moisture contributes to increased vegetation growth, causing decreased substrate moisture under the panels (Bousselot et al. 2013).

Studies of GRIPV

Placing PV panels over green roofs can be one way to directly test the effects of shade on green roofs, but until now there have been very few studies of the effects of PV panels on green roofs, and these studies lack replicate plots, which limits inference. Nevertheless, they still provide useful evidence of how PV arrays should affect the plant and animal community structure. Köhler et al. (2007) compared vegetation communities on a green roof in Germany before and after the PV panel installation, and between a green roof area with, and a separate green roof area without, PV panels on a single roof. Their results suggest that there is higher plant diversity, increased plant height, and lower sedum cover under panels, and that some species benefited from the presence of PV panels. Similarly, a study of a large green roof including sections with PV panels in London suggested that the proportion of bare ground decreased over a season in open areas, while under PV panels, the proportion remained consistently low (Nash et al. 2016). Nash et al. (2016) also found that plant diversity and vegetation height was generally higher at the low edge of PV panels compared to other areas of the green roof, though results varied by season.

On a green roof in Boulder, Colorado, USA, PV panels were placed along one side of a roof and plant populations under the PV panels were compared to the other part of the green roof that was not shaded by panels (Bousselot et al. 2013). They found that the soil moisture was higher in the unshaded area, because there was less vegetation, and in turn lower water use in this area (Bousselot et al. 2013). Overwinter survival was higher under panels (Bousselot et al. 2013), indicating that panels may provide benefits also in cold and moist climates, where protection from drought stress is not needed. Vegetation cover was higher under panels only in substrate without zeolites, a microporous mineral structure which holds nutrients less effectively (Bousselot et al. 2013), possibly because without nutrient limitation, non-shaded plants could also achieve maximum growth. Dry weight was lower under PV panels than in the exposed area, but the water weight was higher in the vegetation under panels, with zeolites in the substrate (Bousselot et al. 2013), indicating that more water was available to plants under panels.

Indirect and direct effects of PV on green roof arthropods

The effects of PV panels on plant biomass and diversity on green roofs may affect the arthropod community on the roof. We provide some examples from studies of the effects of plant diversity and biomass on arthropod communities on the ground, as these can provide some insight into the expected effects of plant community changes on arthropod communities on a green roof. An increase in the plant diversity and the biomass may cause an increase in the overall arthropod abundance and the diversity (Haddad et al. 2001; Haddad et al. 2009). If the presence of PV panels also causes greater diversity of vegetation height, this can also create a diversity of microhabitats that may affect the abundances of specific arthropod species (Joern 1982), and the abundance and the diversity of spiders (Greenstone 1984; McDonald 2007). A comparison of arthropod abundances near PV panels and in open areas of a green roof suggested that the spider abundance was higher near panels, while Hymenoptera and Diptera abundances were higher in the open, and beetle abundances were similar between the two zones (Nash et al. 2016).

If the integration of PV panels with a green roof will result in higher plant diversity, this may also lead to a decrease in herbivore density, via reduction in the density of the host plant species (Wilsey & Polley 2002; Duffy et al. 2007; Haddad et al. 2009), or an increase in the herbivore abundance because of the increased availability of resources overall (Haddad et al. 2001). Predator abundance is expected to increase with increasing plant biomass (Haddad et al. 2009). Given the complexity of interactions among the different trophic levels, it is difficult to make predictions about the indirect effects of panels via plant communities on arthropod communities.

In addition, PV panels may have direct effects on arthropod communities, as some species choose to forage or oviposit in the microclimate created by the panels. The positive microclimatic effects of panels on plant communities may apply to some arthropods as well. Studies in ground level habitats suggest that arthropod richness would be higher in the shade than in the sun (López-Gómez & Cano-Santana 2010), and particularly when non-shaded environments are dry and warm, some spider taxa may benefit from the temperature and the moisture effect of shade (Uetz 1979). In addition, a study of the effects of forest thinning suggests that more heterogeneous environments, created by heavily thinning forests in this case, may have a higher abundance of ground-dwelling arthropods than fully shaded environments (Yi & Moldenke 2005). On the other hand, the polarized light produced by PV panels may attract certain aquatic insects that attempt to lay eggs on such surfaces, and other insect species that use polarized light in orientation during migration (Horváth et al. 2009). Thus, the panels could act as an ecological trap for these insects, increasing their population size on the roof temporarily, but potentially reducing their population size on a larger spatial scale.

Conclusions and future directions

While previous empirical studies of GRIPV have contributed to our predictions of the effect of PV panels on green roofs, the lack of true replicates separated in space has created a confounding effect between the location and the treatment, and consequently, has limited strong inference. Therefore, replicated studies where plots are randomized or randomized within blocks are necessary to strengthen our inference of the effects of PV panels on green roofs. Nonetheless, combining evidence from these studies, on-ground studies of non-PV shade, and ecological theory, we can hypothesize that PV would have a positive effect on the growth of some plant species in dry environments, and that a mixture of areas with different degrees of shade and no shade will enhance the plant diversity on a green roof.

In addition to testing these hypotheses, future studies can provide information that will help optimize designs for GRIPV to maximize the PV panels' efficiency. Plant species diversity, and traits, such as shade tolerance of the specific species chosen, may affect the panel efficiency. The watering regime of plants may also affect panels directly by affecting the temperature of the panels, and indirectly by affecting the plant species selection and the plant biomass. The ratio of green roofs to panels could also affect the green roof's ability to cool the panels, while also affecting the diversity of microhabitats available for plants and insects. There may be a tradeoff between obtaining the optimal PV panel efficiency, with a watered roof that is green year round, and creating a diverse native green roof that provides habitat for local species of plants, insects, and birds, but is brown part of the year, and not transpiring year round. Future studies first need to determine the overall effects of PV panels on green roof communities, and second determine how specific characteristics of the panels and green roof interact with each other.

Acknowledgements

We thank Howard Wenger, Amiel Vasl, Amots Dafni, and Gary Grant for fruitful discussions.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Kadas Green Roofs Ecology Center, University of Haifa, Council for Higher Education, and Ministry of Absorption grants to B.Y.S., Israel Ministry of Environmental Protection grant to Leon Blaustein and Lior Blank, and the EU FP7 funded project TURAS (Transitioning towards Urban Resilience and Sustainability) [grant number: 282834] to Gyongyver Kadas.

ORCID

Shay Levy http://orcid.org/0000-0002-2439-5014

References

Benvenuti S, Bacci D. 2010. Initial agronomic performances of Mediterranean xerophytes in simulated dry green roofs. Urban Ecosystem. 13:349–363.

Bertness MD, Callaway R. 1994. Positive interactions in communities. Trends Ecol Evol. 9:191–193.

Blank L, Carmel Y. 2012. Woody vegetation patch types affect herbaceous species richness and composition in a Mediterranean ecosystem. Community Ecol. 13:72–81.

Bousselot J, Slabe T, Klett J, Koski R. 2013. Exploring Green Roof Plant Survivability in Semi-Arid High Elevation: Photovoltaic Array Influences the Growth of Green Roof Plants. Paper presented at: Cities Alive: 11th Annual Green Roof & Wall Conference; San Francisco, USA.

Breshears DD, Ludwig JA. 2010. Near-ground solar radiation along the grassland-forest continuum: Tall-tree canopy architecture imposes only muted trends and heterogeneity. Austral Ecol. 35:31–40.

Brooker R, Callaghan T. 1998. The balance between positive and negative plant interactions and its relationship to environmental gradients: a model. Oikos. 81:196–207.

Callaway R. 1994. Facilitative and interfering effects of *Arthrocnemum subterminale* on winter annuals. Ecology. 75:681–686.

Callaway R. 1995. Positive interactions among plants. Bot Rev. 61:306−349.

Chemisana D, Lamnatou C. 2014. Photovoltaic-green roofs: an experimental evaluation of system performance. Appl Energy. 119:246−256.

Collier M, Nedović-Budić Z, Aerts J, Connop S, Foley D, Foley K, Newport D, McQuaid S, Slaev A, Verburg P. 2013. Transitioning to resilience and sustainability in urban communities. Cities. 32:S21−S28

Cook-Patton SC, Bauerle TL. 2012. Potential benefits of plant diversity on vegetated roofs: a literature review. J Environ Manage. 106:85−92.

Dewey D, Johnson P, Kjelgren R. 2004. Species composition changes in a rooftop grass and wildflower meadow: implications for designing successful mixtures. Native Plants J. Spring: 56−65.

Duffy JE, Cardinale BJ, France KE, McIntyre PB, Thébault E, Loreau M. 2007. The functional role of biodiversity in ecosystems: incorporating trophic complexity. Ecol Lett. 10:522−538.

Getter KL, Rowe BD. 2006. The role of extensive green roofs in sustainable development. HortScience. 41:1276−1285.

Getter KL, Rowe BD, Cregg BM. 2009. Solar radiation intensity influences extensive green roof plant communities. Urban For Urban Greening. 8:269−281.

Greenstone M. 1984. Determinants of web spider species diversity: vegetation structural diversity vs. prey availability. Oecologia 62:299−304.

Grime J. 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. Am Naturalist. 111:1169−1194.

Haddad NM, Crutsinger GM, Gross K, Haarstad J, Knops JMH, Tilman D. 2009. Plant species loss decreases arthropod diversity and shifts trophic structure. Ecol Lett. 12:1029−1039.

Haddad NM, Tilman D, Haarstad J, Ritchie M, Knops JM. 2001. Contrasting effects of plant richness and composition on insect communities: a field experiment. Am Naturalist. 158:17−35.

Horváth G, Kriska G, Malik P, Robertson B. 2009. Polarized light pollution: a new kind of ecological photopollution. Front Ecol Environ. 7:317−325.

Hui SCM, Chan KL. 2011. Biodiversity assessment of green roofs for green building design. Paper presented at: Proceedings of Joint Symposium 2011: Integrated Building Design in the New Era of Sustainability; Hong Kong.

Joern A. 1982. Vegetation structure and microhabitat selection in grasshoppers (Orthoptera, Acrididae). Southwest Naturalist. 27:197−209.

Köhler M, Wiartalla W, Feige R. 2007. Interaction Between PV-Systems and Extensive Green Roofs. Paper presented at: 5th Annual Greening Rooftops for Sustainable Communities Conference; Minneapolis, USA.

Lamnatou C, Chemisana D. 2015. A critical analysis of factors affecting photovoltaic-green roof performance. Renewable Sustainable Energy Rev. 43:264−280.

López-Gómez V, Cano-Santana Z. 2010. Best host-plant attribute for species-area relationship, and effects of shade, conspecific distance and plant phenophase in an arthropod community within the grass *Muhlenbergia robusta*. Entomol Sci. 13:174−182.

Lundholm J, MacIvor J, MacDougall Z, Ranalli M. 2010. Plant species and functional group combinations affect green roof ecosystem functions. PLOS One. 5:e9677.

MacIvor JS, Lundholm J. 2011. Insect species composition and diversity on intensive green roofs and adjacent level-ground habitats. Urban Ecosyst. 14:225−241.

McDonald B. 2007. Effects of vegetation structure on foliage dwelling spider assemblages in native and non-native Oklahoma grassland habitats. Proc Oklahoma Acad. 88:85−88.

Meral ME, Dinçer F. 2011. A review of the factors affecting operation and efficiency of photovoltaic based electricity generation systems. Renewable Sustainable Energy Rev. 15:2176−2184.

Myhrvold NP, Caldeira K. 2012. Greenhouse gases, climate change and the transition from coal to low-carbon electricity. Environ Res Lett. 7:014019.

Nagengast A, Hendrickson C, Matthews HS. 2013. Variations in photovoltaic performance due to climate and low-slope roof choice. Energy Buildings. 64:493−502.

Nash C, Clough J, Gedge D, Newport D, Ciupala MA, Connop S. 2016. Initial insights on the biodiversity potential of biosolar roofs: a London Olympic Park green roof case study. Israel J Eco Evol. 62(1−2):74−87.

Pearlmutter D, Rosenfeld S. 2008. Performance analysis of a simple roof cooling system with irrigated soil and two shading alternatives. Energy Buildings. 40:855−864.

Perez M, Wight N, Ho C, Fthenakis V. 2012. Green-Roof Integrated PV Canopies — an Empirical Study and Teaching Tool For Low Income Students in the South Bronx. Paper presented at: World Renewable Energy Forum; Denver, CO, USA.

Saiz S, Kennedy C, Bass B, Pressnail K. 2006. Comparative life cycle assessment of standard and green roofs. Environ Sci Technol. 40:4312−4316.

Scherba A, Sailor DJ, Rosenstiel TN, Wamser CC. 2011. Modeling impacts of roof reflectivity, integrated photovoltaic panels and green roof systems on sensible heat flux into the urban environment. Building Environ. 46:2542−2551.

Siemann E. 1998. Experimental tests of effects of plant productivity and diversity on grassland arthropod diversity. Ecology. 79:2057−2070.

Speak AF, Rothwell JJ, Lindley S J, Smith CL. 2012. Urban particulate pollution reduction by four species of green roof vegetation in a UK city. Atmospheric Environ. 61:283−293.

Tan PY, Sia A. 2005. A pilot green roof research project in Singapore. Paper presented at: Third Annual Greening Rooftops for Sustainable Communities Conference; Boston, MA, USA.

Ubertini S, Desideri U. 2003. Performance estimation and experimental measurements of a photovoltaic roof. Renewable Energy. 28:1833−1850.

Uetz G. 1979. The influence of variation in litter habitats on spider communities. Oecologia. 40:29−42.

Valladares F, Niinemets Ü. 2008. Shade tolerance, a key plant feature of complex nature and consequences. Annu Rev Ecol Evol Syst. 39:237−257.

Vasl A, Heim A. 2016. Preserving plant diversity on extensive green roofs – theory to practice. Israel. J Ecol Evol. 62(1−2):103−111.

Wilsey BJ, Polley HW. 2002. Reductions in grassland species evenness increase dicot seedling invasion and spittle bug infestation. Ecol Lett. 5:676−684.

Witmer L. 2010. Quantification of the passive cooling of photovoltaics using a green roof [thesis]. University Park (PA): The Pennsylvania State University.

Yi H, Moldenke A. 2005. Response of ground-dwelling arthropods to different thinning intensities in young Douglas fir forests of western Oregon. Environ Entomol. 34:1071−1080.

Zavala M, Espelta J, Retana J. 2000. Constraints and trade-offs in Mediterranean plant communities: the case of holm oak-Aleppo pine forests. Bot Rev. 66:119−149.