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Projecting the Impact of Climate Change on Outdoor Thermal Human Comfort in the Middle East

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Abstract
Climatic changes have enhanced the global frequency of extreme weather episodes such as storms, cold spells, heat waves, floods and droughts. These extreme events potentially impact the health condition of people and increasing risk diseases. The eastern and southern Mediterranean, will be more affected by climate change than other regions of the glob during the 21st century. This article critically projects the thermal human comfort at Tulkarm, Haifa Airport and Ben-Gurion Airport. Climate projection of ECHAM5 model, applying scenario RCP4.5 are compared to observation and there consequences in future thermal comfort are discussed. Climate projections of the thermal comfort is assessed by help of the physiologically equivalent temperature (PET), the thermal discomfort index (DI), and the universal thermal climate index (UTCI) for the year 2030 are assessed. In result, the application of PET, UTCI and DI to climate projections indicated that all regions will comparably suffer from thermal discomfort during summer months. The values of Discomfort index (DI) in Haifa Airport and Tulkarm is very similar and nearly identical. In Ben-Gurion Airport, thermal discomfort tends to increase, especially from May to September. The global trend of long-term warming continuous. The Middle East, like the rest of the world, suffers from climate change.

1. Introduction
Urban Heat Island, this phenomenon related to a higher atmospheric temperature occurring in urban areas than in the surrounding rural areas due to urbanization [1,2]. The atmospheric UHI often reaches its strongest intensity on summer nights and developing under calm air and a cloudless sky. The existence of tall building in urban areas provides surface reflection, and cause blocking of winds which may inhibit cooling by convection thus modifying patterns of airflow over the city [3]. Unkasevic *et al.* [4] found that relative humidity and water vapor pressure in Belgrade which is urban area is drier than rural areas in the afternoon throughout the year. The strong relation found between the urbanization and industrialization [5]. Industrial air pollution and deforestation have greatly increased the concentrations of, carbon dioxide, methane, and nitrous oxide, all greenhouse gases that help trap heat near Earth's surface. The different microclimates condition in the city influences also on outdoor human comfort. The most important environment factors that produce heat stress are temperature and relative humidity.

The Mediterranean region is likely to experience substantial climatic change in future [6] their urban districts will become "hot-spots" of climate change related risks. These perils comprise coastal erosion and coastal flooding [7], droughts [8], water scarceness [9], air pollution [10], and heat. Just now, the heat related effects in cities, such as the urban heat island (UHI) and the thermal human comfort, came to the emphasis of urban environmental research [11], particularly in the zone between Jordan and Mediterranean coast that is among the most susceptible regions. In 2012, the Intergovernmental Program on Climate Change (IPCC) reported that, in the Mediterranean basin there is an increase in warm days and nights, in parallel with a reduction in cold days and nights [12].
The present study aims to predictions of thermal human comfort for 2030 based on data collected from ECHAM5 model, scenario RCP4.5 for three selected sites.

2. Material and Methods

The Meteorological data were obtained from three weather stations (Figure 1): Tulkarm, Haifa Airport and Ben-Gurion Airport. Mean monthly data of air temperature (°C), relative humidity (%) and wind speed (km/h), were gathered from Palestinian Meteorological Department and historical weather data records of Israel (Global climate data at www.en.tutiempo.net/climate).
Air temperatures were measured by dry bulb mercury thermometers sheltered from direct solar radiation 2m above ground level with an accuracy of 0.1°C. Hygrometers registered relative humidity.
Thermal comfort was assessed by three indicators: Physiological Equivalent Temperature (PET) (based on the numerical radiation model RayMan [13]; calculations were made at 12 pm and in the mid of each month); Discomfort Index [14] calculated according to $DI = Ta - (0.55 - 0.0055*RH) (Ta - 14.5)$ from the mean monthly temperature (Ta in °C) and the mean monthly relative air humidity (RH in %); Universal Thermal Climate Index (UTCI)(www.utci.org). projections were calculated for the period 2010-2030 using the ECHAM5 model data and applying the RCP4.5 scenario. ECHAM5 is a general circulation model (GCM) used in the IPCC Fourth Assessment Report. ECHAM5 [15] is the 5thgeneration of the ECHAM general circulation model evolving originally from the spectral weather prediction model of the European Centre for Medium Range Weather Forecasts. In climate change research, scenarios describe the potential consequences of anthropogenic climate change. The new scenarios are called Representative Concentration Pathways (RCPs), which concern of greenhouse gas concentration and emissions pathways designed to support research on impacts of climate changes [16,17]. The four RCPs included one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5/RCP6) and one very high baseline emission scenarios (RCP8.5). There are four pathways: RCP8.5, RCP6, RCP4.5 and RCP2.6 that lead to radiative forcing levels of 8.5, 6, 4.5 and 2.6 W/m². The scenario applied in this research is RCP4.5, which was developed by the MiniCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI, www.globalchange.umd.edu). The radiative forcing is stabilized before 2100 by application of a technologies and strategies for reducing greenhouse gas emissions [18,19]. The data were collected from ECHAM5 model for the period 2015 to 2030 and comprise, mean monthly air temperature, relative humidity and wind speed.

3. Study Areas

Tulkarm is a town situated on the western part of the northern West Bank (32º19 N, 35º01 E, 83m a.s.l.). Located about 40 km south of Haifa, 25 km north of Tel Aviv and about 14 km away from the Mediterranean Sea. Affected by Mediterranean climate, Tulkarm has a yearly rainfall of 568 mm limited to the winter; relative humidity is on average 60%, and average temperatures range from 8 to 18 °C in winter, and from 23 to 31 °C in summer that is moderated by the sea breeze (Palestinian Meteorological Department).

Tel Aviv International Airport (Ben-Gurion) (32°0'1.16"N and 34°52'13.63"E, 40 m a.s.l.) is located nearly 18 km away from Mediterranean Sea and faraway 19 km from Tel Aviv city. Temperatures typically vary from 8 °C to 32 °C. The average summer temperature in Tel Aviv is 25 °C, and the average winter temperature is 14°C. Precipitation during the summer is rare, winters are mild and wet. Relative air humidity ranges from 37 % to 94 % over the year, the driest months are April and May when relative humidity is dropping below 16 %, while the most humid month is February exceeding 89% (Israel Meteorological Service). There is a very vast open area around the Airport runway.

Haifa International Airport (32° 47' 38.5584" N, 34° 59' 22.4556" E, 9 m a.s.l.) is situated on the Mediterranean coastline. Haifa International Airport is nearly 10 km east of Haifa city. Over the course of a year, the temperature typically varies from 11 °C to 32 °C and is rarely below 8 °C or above 33 °C. The hottest month of the year is July, with average maxima of 32°C and minima 26 °C. The coldest month of the year is January, with average minima of 11°C and maxima 18 °C (Israeli Meteorological Service). Relative humidity typically ranges from 35 % to 85 % over the course of the year, rarely dropping below 20%.

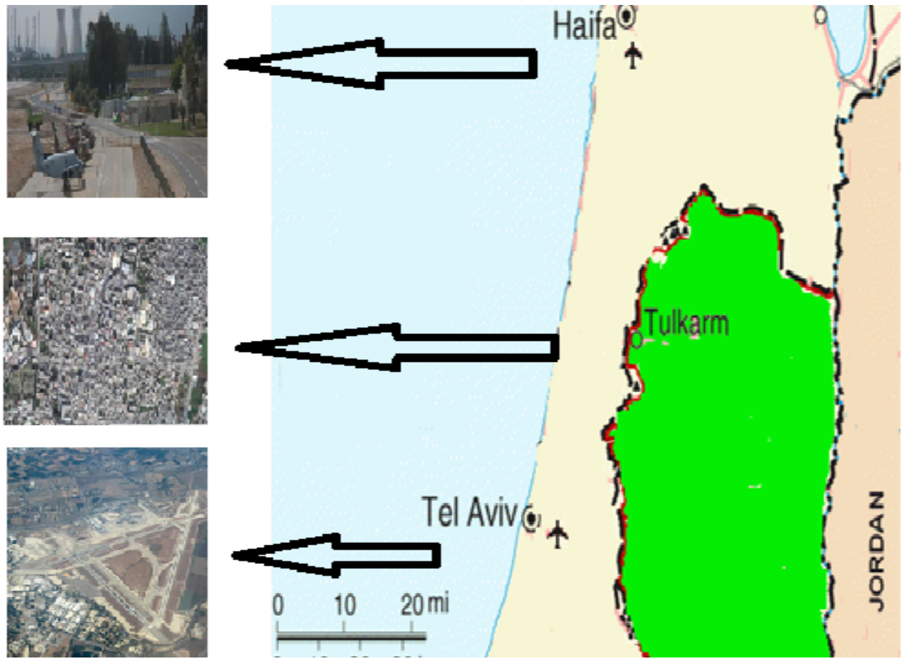

Figure 1: The location of the three selected sites.

4. Results and discussion

Comparing the observations of the period 2010-2014 with ECHAM5 projections we calculated the Root Mean Square Error ($RMSE = \sqrt{\frac{\Sigma(OBS-MOD)^2}{N}}$ and the $Pencentage\ of\ Error\ (\%) = \frac{RMSE}{N}*100$ for the three study areas (N is the number of months). To describe the associations between the observations OBS and the predictions MOD a regression line was fitted (OBS = a * MOD + b; where b = slope and a = intercept). Finally, we calculated the human comfort indexes for the predictions at the three selected stations for the period 2015-2030. We found that in the summer months there is a big difference between modeled and observed data (Table 1). RMSE shows higher values of relative humidity over Tulkarm and Haifa Airport compared to Ben-Gurion Airport. Also, the percentage of error shows higher values of relative humidity over Tulkarm and Haifa Airport.

Table 1: RMSE and percentage of error for climatic observations during 2010 to 2014.

PARAMETERS/ AREAS	TULKARM	HAIFA	BEN-GURION
AIR TEMPERATURE	RMSE = 2.8 Percentage of error = 5%	RMSE = 2.4 Percentage of error =4%	RMSE = 1.7 Percentage of error =3%
RELATIVE HUMIDITY	RMSE = 18.1 Percentage of error =30%	RMSE =17.9 Percentage of error =30%	RMSE =7.8 Percentage of error =13%
WIND SPEED	RMSE = 3.9 Percentage of error =7%	RMSE =1.9 Percentage of error =3%	RMSE = 2.7 Percentage of error =5%

Recent runs of the ECHAM4 and HadCM3 GCMs under the B2 emissions scenario confirm substantial temperature increases of up to 4ºC for the eastern Mediterranean region [20].

The thermal human comfort indexes analyzed in this study are nearly similar in almost all stations and representative of the thermal sensations in the three different metropolitan regions (Table 2 and Table 3). This group of indices had two or three meteorological variables in the equation. The most used indicator of thermal comfort is air temperature and relative humidity, it is easy to use and most people can relate to it. However, air temperature alone is not a valid or accurate indicator of thermal comfort or thermal stress.

Table 2: Monthly Physiologically Equivalent Temperature (PET) averages (in ºC) at selected stations under RCP4.5 model from 2015-2030.

MONTHS	TULKARM	HAIFA AIRPORT	BEN-GURION AIRPORT
JAN	18.9	15.9	11.2
FEB	18.7	16.2	13
MAR	20.4	17.8	16.5
APR	21.5	19.4	20.4
MAY	23.1	21.1	24.3
JUN	25.9	24.9	29.5
JUL	27.3	26.6	32.1
AUG	27.9	27.2	32.1
SEP	27.9	26.6	29.3
OCT	27.4	23.7	24.1
NOV	25.5	19.7	17.7
DEC	22.5	16.9	12.5

This study shows that physiologically equivalent temperature is more accurate and precise, because the four components, wind speed, air temperature, relative humidity and vapour pressure were used in this index. The Ben-Gurion Airport is heading for an increase in discomfort, especially from May to September (Figure 2 and Figure 3). Tulkarm and Haifa Airport have nearly similar thermal discomfort during summer months. Relative humidity in the Tulkarm is very high compared to the Ben-Gurion Airport.

As shown in Table 4, suggests that, the Discomfort Index (DI) has a higher number of comfortable months compared to Physiologically Equivalent Temperature (PET). Mandelmilch *et al.* [21] examine the intensity of the heat exposure in Tel Aviv finding that, the southern district is 6-8 °C hotter than the northern neighborhoods and summer daily UHI of 3.6 °C. The highest peaks values considered for selected indexes of the Tulkarm, Ben-Gurion and Haifa Airport were found in the months of July and of August (Figure 2).

Table 3: Discomfort Index averages (in ºC) for climate change under RCP4.5 model at three selected station from 2015 to 2030.

MONTHS	TULKARM	HAIFA AIRPORT	BEN-GURION AIRPORT
JAN	17.8	17.3	12.4
FEB	17.6	17	13.1
MAR	18.1	17.7	15.3
APR	19.2	18.8	18
MAY	20.7	20.4	20.4
JUN	22.3	22.1	22.7
JUL	23.2	23.1	24.1
AUG	23.6	23.4	24.1
SEP	23.1	23	22.7
OCT	22.1	22.1	20.5
NOV	20.4	20.2	17
DEC	18.8	18.4	13.4

Table 4: Percentage of comfortable months in Ben-Gurion Airport as estimated by the two indices during 2015-2030.

INDEXES	COMFORTABLE MONTHS
DISCOMFORT INDEX (DI)	April, May
PHYSIOLOGICAL EQUIVALENT TEMPERATURE (PET)	April

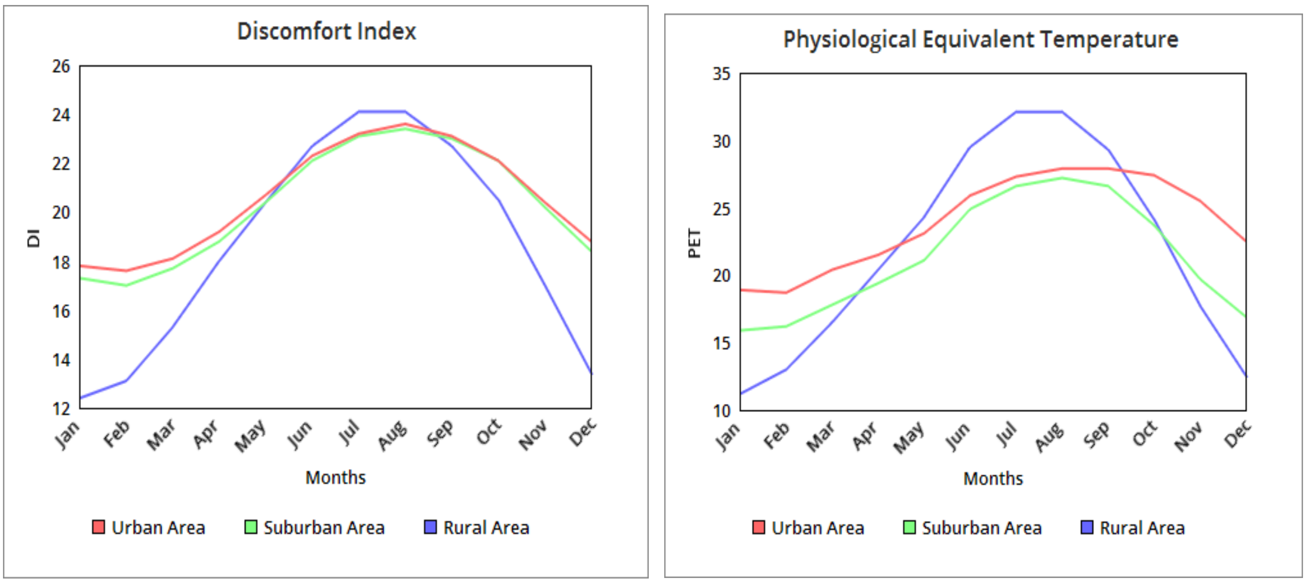

Figure 2: Average monthly pattern of Discomfort Index (DI, left) and Physiologically Equivalent Temperature (PET, right) at study sites predicted for the years 2015-2030.

Summarizing the results, we found that, Applying PET and DI to climate predictions for 2015-2030 (using RCP4.5 scenarios) indicates that in Ben-Gurion Airport the thermal discomfort tends to increase, especially from May to September. Thermal comfort in Tulkarm and Haifa Airport is very similar and nearly identical during summer months. The highest PET and DI values in the Ben-Gurion Airport are 32.1 °C and 24.1 °C, respectively in July and August.

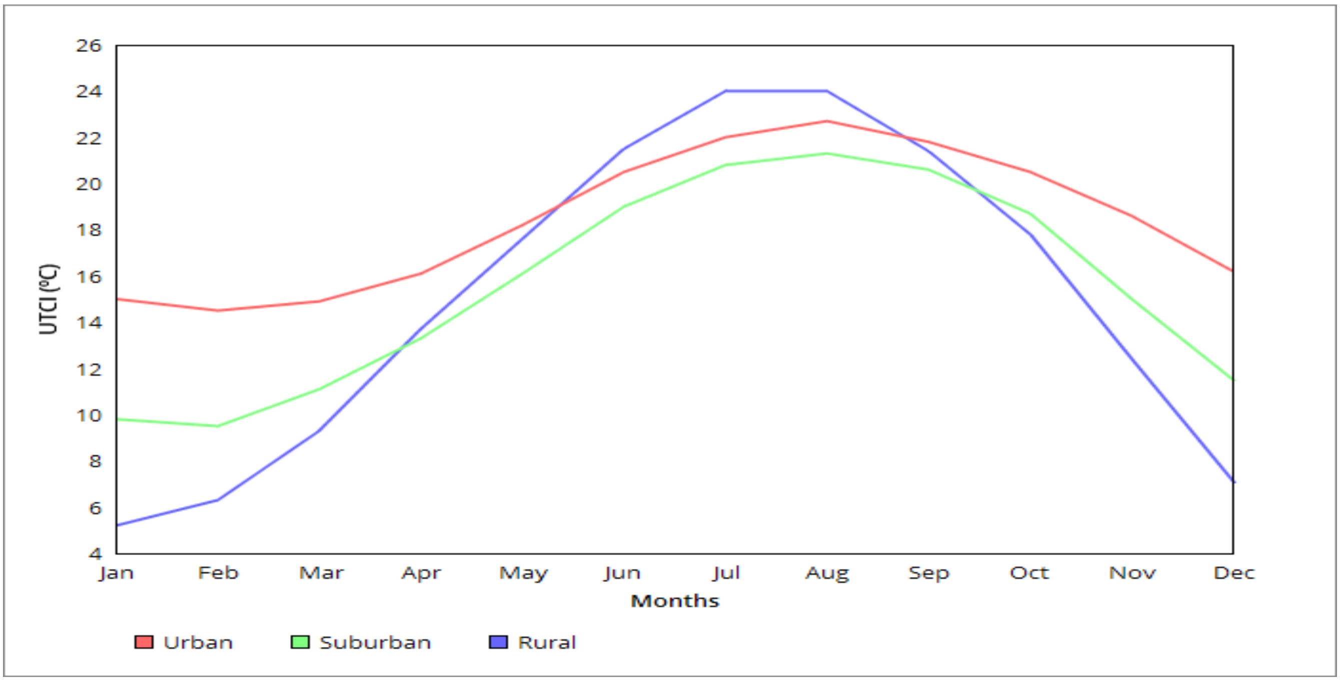

Figure 3: Average monthly pattern of Universal Thermal Climate Index (UTCI)(in °C) at study sites predicted for the years 2015-2030.

Air pollution caused by Haifa's Port plays a major role in the emission of dangerous pollutants in the area and incidence of several cancers in Haifa district were above national average rates in 1984-1999 [22]. There is need to adapt to climate change and cities often have strong management and planning systems they can be restructured and reorganized over time [23].

Conclusion

Long term global warming trend continues. The study of future climate change found that, significant warming occurred at all stations but the warming being significantly larger at the Ben-Gurion Airport. Ben-Gurion Airport experienced the highest values of PET and DI compared to Tulkarm and Haifa Airport. The Ben-Gurion Airport is heading for an increase in thermal discomfort.

Besides the urban structure of Tulkarm that is impaired by the Separation Wall, a huge portion of land in the west part of the city, which was originally used for agricultural activities, was confiscated for the construction of the Separation Wall. At the same time, the city expansion is restricted along the west side of the city.

The local climate is presumably also affected by nearby pollution sources in both Haifa Airport and Ben-Gurion Airport.

References

1. J. A. Voogt, T. R. Oke, Thermal remote sensing of urban areas. *Remote sensing of environment,* 86 (2003) 370-384. https://doi.org/10.1016/S0034-4257(03)00079-8

2. G. Mills, Cities as agents of global change. *International Journal of Climatology* 27 (2007) 1849-1857
3. V. Daniele, Urban Planning and design for local climate mitigation. *46th ISOCARP congress*, (2010) Nairobi, Kenya. Retrieved from *http://www.isocarp.net/Data/case_studies/1815.pdf*.
4. M. Unkasevic, O. Jovanovic and T. Popovic, Urban – suburban / rural vapour pressure and relative humidity differences at fixed hours over the area of Belgrade city. *Theor: Appl. Climatol.* 68 (2001) 67-73.
5. Daron Acemoglu, Simon Johnson, and James A. Robinson, Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution. *Journal of Economics*,117(4) (2002) 1231–1294.
6. G. Smiatek, H. Kunstmann, A. Heckl, High-resolution climate change simulations for the Jordan river area. *Journal of Geophysical Research-Atmospheres* 116, (D16) D24123 (1-14) (2011).
7. A. Satta, M. Puddu, S. Venturini, C. Giupponi, Assessment of coastal risks to climate change related impacts at the regional scale: The case of the Mediterranean region. *International Journal of Disaster Risk Reduction* 24 (2017) 284-296. https://doi.org/10.1016/j.ijdrr.2017.06.018
8. D. Gampe, A. R. Ludwig, K. Qahman, S. Afifi, Applying the triangle method for the parameterization of irrigated areas as input for spatially distributed hydrological modeling –assessing future drought risk in the gaza strip (Palestine). *Sci Total Environ* 543 (2016) 877-888. https://doi.org/10.1016/j.scitotenv.2015.07.098
9. J. Selby, C. Hoffmann, Water scarcity, conflict, and migration: A comparative analysis and reappraisal. *Environment and Planning C-Government and Policy* 30 (2012) 997-1014. https://doi.org/10.1068%2Fc11335j
10. J. Heo, B. Wu, Z. Abdeen, R. Qasrawi, J. A. Sarnat, G. Sharf, Source apportionments of ambient fine particulate matter in Israeli, Jordanian, and Palestinian cities. *Environ Pollut* 225 (2017) 1-11. https://doi.org/10.1016/j.envpol.2017.01.081
11. O. Potchter, H. I. Ben-Shalom, Urban warming and global warming: Combined effect on thermal discomfort in the desert city of beer sheva, israel. *Journal of Arid Environments* 98 (2013)113-122. https://doi.org/10.1016/j.jaridenv.2013.08.006
12. Intergovernmental Panel on Climate Change (IPCC): Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge and New York: *Cambridge University Press*; 582 PP (2012).
13. A. Matzarakis, F. Rutz, H. Mayer, Modelling Radiation fluxes in simple and complex environments – Application of the RayMan model. *International Journal of Biometeorology* 54 (2010) 131-139. https://doi.org/10.1007/s00484-009-0261-0
14. E. C. Thom, The discomfort index. *Weather wise*, 12 (1959) 57-60. https://doi.org/10.1080/00431672.1959.9926960
15. E. Roeckner, G. Bäuml, The atmospheric general circulation model echam5, part i: Model description. *Max Planck Institute for Meteorology* 349 (2003). https://mpimet.mpg.de/fileadmin/models/echam/mpi_report_349.pdf
16. R. H. Moss, J. A. Edmonds, K. A. Hibbard, M. R. Manning, S. K. Rose, D. P. Van Vuuren, T. R. Carter, S. Emori, M. Kainuma, T. Kram, G. A. Meehl, J. F. Mitchell, N. Nakicenovic, K. Riahi, S. J. Smith, R. J. Stouffer, A. M. Thomson, J. P. Weyant, T. J. Wilbanks, The next generation of scenarios for climate change research and assessment. *Nature*. 463 (2010) (7282) 747-56. https://doi.org/10.1038/nature08823

17. D. P. Van Vuuren and K. Riahi, The relationship between short-term emissions and long-term concentration targets—a letter. *Climatic Change*, 104(3–4) (2011) 793–801. https://doi.org/10.1007/s10584-010-0004-6
18. L. Clarke, J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels, Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, *Office of Biological & Environmental Research*, Washington, (2007)7 DC., USA, 154 pp.
19. M. A. Wise and J.J. Dooley, The Value of Post-Combustion Carbon Dioxide Capture and Storage Technologies in a World with Uncertain Greenhouse Gas Emissions Constraints. *International Journal of Green House Gas Control*, 3(2009) 39-48.
20. E. Hertig and J. Jacobeit, Downscaling future climatic change: temperature scenarios for the Mediterranean area", *Global and Planetary Change* 63(2-3) (2008) 127-131. https://doi.org/10.1016/j.gloplacha.2007.09.003
21. M. Mandelmilch, M. Ferenz, N. Mandelmilch, O. Potchter, Urban Spatial Patterns and Heat Exposure in the Mediterranean City of Tel Aviv. *Atmosphere* 11(9) (2020) (963) 2-19. https://doi.org/10.3390/atmos11090963
22. M. Barchana, Geographical mapping of malignant diseases in Israel 1984–1999. *Israel National Cancer Registry*, Tel Aviv; (2001) [Hebrew].
23. G. Mills, Cities as agents of global change. *International Journal of Climatology,* 27 (2007) 1849-1857. http://dx.doi.org/10.1002/joc.1604

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