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ORIGINAL ARTICLE

White roof as a multiple benefits low-cost technology

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ABSTRACT

The article explores the potential of white roof as an effective solution to address three interrelated problems which are global warming, urban heat island effect, and energy consumption in buildings. First, global warming and urban heat island effects are briefly explained. Later, some geoengineering approaches as potential solutions to such issues are explored. Among various solutions, the white roof technology is analyzed in more depth and its effects on building energy efficiency are investigated. Finally, the experiment carried out at CERN IdeaSquare is presented. According to the results, the application of white roofs in urban areas stands as a compelling, possible alternative.

Keywords: global warming; urban heat island; building energy efficiency; white roof

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INTRODUCTION

Global warming is one of the most worrying manifestations of climate change (Schaltegger, et al., 2011, Princiotta, 2011). It refers to the increase in Earth's average temperature and its multiple effects could be sea levels rising (Moore, et al., 2011, Moore, et al., 2013), droughts (Strauss, F. et al., 2013), increasing hurricane risks (Grinsted, et al., 2013, Mannshardt & Gilleland, 2013) and consequent climatic migrations (World Bank Report, 2018). Global warming is mainly caused by anthropogenic greenhouse gas emissions like carbon dioxide (CO_2). The Assessment Reports by the Intergovernmental Panel on Climate Change (IPCC, 2007, IPCC, 2013) of the United Nations demonstrated that there will be, by 2100, at least a 3°C increase in average on the surface of the globe, from the pre-industrialized era, if a drastic change in the development model is not undertaken (Keller, et al., 2014). Obviously, there is and will increasingly be a heterogeneous temperature repartition depending on the regions and seasons. Climate models are likely among the most complex physical models regarding the degrees of freedom. Consequently, even if the initial conditions of the system are known nowadays (e.g. the disappearance of the Arctic ice cap, the increasing number of climatic catastrophes, etc.), the future remains unknowable and unpredictable. Therefore, if there is a human activity concentration in small spatial regions, there will be an even more increase in the global warming effect. This phenomenon is widely known as the urban heat island effect in intensified urban areas where the average temperature is greater than its surrounding rural areas. Moreover, according to the united Nations report (UN Report, 2018) by 2050 amount of urban dwellers is increased by 13%, that will amplify this frightening phenomenon and overshadows population living conditions.

GEOENGINEERING APPROACH OVERVIEW

To counter this problem, two mutually non-exclusive approaches are being considered. On the one hand, if human beings' destruction of the living ecosystem is to be prevented, a strong adaptation and shift of the development model toward environment centric is mandatory. This encompasses a circular economy, energy transition and economy decarbonization. Unfortunately, this shift is not immediate. Therefore, the scientific community is trying to find short term solutions for giving time to humanity to proceed with this transition. Geoengineering includes all the potential climate engineering solutions which are currently considered to be implemented to slow down global warming and more generally climate change. Depending on where these solutions can be deployed, four different schemes can be enumerated: land-based, ocean-based, atmosphere-based, and space-based geoengineering solutions. Yet, the most differentiation shouldn't be done on the location of the solution but rather on the pursued objective.

Indeed, two fundamental approaches are being undertaken. The first one regards CO_2 capture and recovery using physical, chemical or biological technologies which allow to sequester and remove atmospheric CO_2. This approach includes afforestation and reforestation, biochar production or ocean fertilization exploiting natural plant photosynthesis for example. Nevertheless, it's difficult to imagine effective CO_2 capture and recovery solutions when absorbed CO_2 gains and anthropogenic CO_2 emissions are quantitatively compared. The second geoengineering branch refers to the Solar Radiation Management method. The physical principle behind is to adjust the solar radiation energy absorbed by the Earth through the increase in the planetary albedo index.

By raising the reflective power of the globe, radiative forcing would be cancelled which, as a result, would cool the planet and annihilate global warming. In fact, the scientific community agrees on a white reflective surface from $1*10^6$ to $5*10^6$ km^2 depending on where this solution is spread, is needed to reach the targeted albedo index. Moreover, injecting sulfur dioxide into the stratosphere or putting sun shield in space to block incoming sun light along with introducing aerosols as sodium chloride to increase cloud reflectivity are some other examples of different potential solutions currently investigated by climate researchers (IPCC 2013). Nevertheless, scientific community opinion differ on this topic especially regarding potential climatic local reverse effects above all on precipitation patterns and natural equilibrium destabilization (Niemeier, et al., 2013).

WHITE ROOF AS A SOLUTION

Solar radiation management solution locally applied in cities could tackle both heat urban island and global warming effects minimizing the possible local climatic drawbacks. Rooftops stand as high potential surfaces of intervention in urban areas to increase environmental performance of buildings. The roofs are usually underutilized and require less attention concerning architectural aesthetics within the city compared to building façades. They are the warmest element of the structure since they are exposed to direct sunrays, hence taking care of these envelopes by some retrofitting programs would minimize remarkably the heat gains throughout the entire building. Among various technologies, the simplest and efficient solution is the so-called cool roof technology. A cool roof is characterized by high solar reflectance and high thermal emittance values. Our research focuses on the white roof in the form of white paints or coatings, which can be applied to the existing or new structures. Painting rooftops to white is the quickest solution since it is rather easy to implement and efficient in terms of reflectivity. Significant impacts both on single building energy savings and on the city's overall elevated temperatures are expected by turning existing rooftops to white surfaces.

The solar reflectance of a dark roof and a white roof shows a noticeable difference since the former range from 0.05 to 0.2 and the latter from 0.55 to 0.85 (Urban & Roth 2010). White roofs are better in reflecting back sun rays, namely they reflect 3 to 10 times better the sunlight than grey roofs being able to emit thermal radiation at the same time (Cubi, et al., 2015). Moreover, Altan H. et al. (Altan, et al., 2019) have demonstrated that white roofs improve the solar panel efficiency in the range of 5 to 10%. The increased albedo of white roofs decreases significantly the surface temperature and reduces sensible flux into the urban atmospheric fabric (Scherba, et al., 2011). Furthermore, white roofs reduce the energy needed for cooling, and also reduce the peak electric power demand of cooling. In particular, large-scale installation of white roofs during warm seasons would lower the annual mean heat island effect by 33% and the extreme temperatures by up to 1-2°C in average (Scherba, et al., 2011). A study by the Lawrence Berkeley Laboratory's Heat Island Group indicated that increasing the reflectivity of territorial surfaces (road and roof) in urban areas with populations over 1 million would help to reduce 1.2 gigatons of carbon dioxide annually (Heat Island Group, 2019).

The benefits are accompanied with some drawbacks as well. Firstly, the reduction of solar gains in winter season with a possible increase in heating need (known as heating penalty) and secondly, the creation of glare from the white roof of a lower building toward the façade of taller buildings with an unwanted heat creation for the neighbors (Urban & Roth 2010; Levinson & Akbari 2010). Nevertheless, some scholars point out that the heating penalty is usually outweighed by the cooling benefit since winter days are shorter and sun rays are less direct (Bretz & Akbari 1997).

Recently, cities have been taking initiatives to create reflective surfaces by exploiting roofs. New York, Chicago, Los Angeles, and Melbourne are some of the municipalities that promote cool roof initiatives and policies. Indeed, Chicago and Los Angeles started a program to color asphalt road surfaces into light grey. In Melbourne, dwelling owners are being encouraged to apply cool-roof technologies for obtaining building benefits. The city of New York, in 2008, introduced a new rule into its building codes in favor of white roofs. The 2008 NYC Building Code requires buildings to have 75 percent of the roof surface covered with a reflective, white coating or to be ENERGY STAR® rated as highly reflective. They require a minimum initial solar reflectance of 0.7 and a minimum thermal emittance of 0.75 (NY building code, 2008). Thus, the city expects a significant increase in white roof surfaces by 2030. White roof initiatives are therefore expected to rise more and more at the municipal scale as a new urban strategy for mitigating urban heat island and global warming effects that will globally shape contemporary cities.

BUILDING SCALE LITERARY RESULTS

This section aims to investigate the principal results that have been reached over the world in terms of energy saving for single-story buildings by applying white roof technologies. The research can be divided mainly into two groups, namely field studies and simulation-based studies (Testa, 2017).

Field studies are based on the monitoring of the cooling energy demand of a building before and after a white roof retrofit intervention. For this group, a review of the results are reported in Table 1. In particular, Table 1 represents the daily cooling energy saving for different kinds of buildings in warm regions of the US. The results show daily cooling energy reduction in the range of 6 to 29%.

Tab. 1. Summary of performance of cool roofs based on field studies for US buildings (Testa, 2017).

Location	Reference	Building Type	Roof Area [m^2]	Energy saving [%]
California				
Davis	Konopacky S,1998	Medical office	2945	12
Gilroy	Konopacky S,1998	Medical office	*2211*	*8*
San Jose	Konopacky S,1998	Retail store	3056	9
Sacramento	Ahbari H, 1997	School bungalow	89	*20*
Sacramento	Ahbari H, 1997	Residence	167	*25*
San Marcus	Ahbari H, 2001	Elementary school	*570*	*12*
Reedley	Ahbari H, 2001	Cold storage	4900	*6*
Florida				
Cocoa Beach	Parker D. 1997	Strip mall	1161	29
Cape Canaveral	Parker D. 1998	Residence	130	*12*
Texas				
Austin	Konopacky S, 2001	Retail store	9300	*14*

Simulation studies are based on modeling and numerical simulation analyses. Unlike the field studies, simulations often investigate the effects of cool white roofs on both cooling energy savings and heating penalties in various climates. In particular, Konopacki et al. (Konopacki et al., 2001) considered in their analysis 240 different locations across the United States and 6 building types: new/old residential, new/old office building, and new/old retail. These building types represent 93% of the US building stock (Konopacki S. 1997). The simulation results are listed in Table 2 in which the ranges represent the results for different locations.

Tab. 2. Summary of performance of cool roofs based on simulation-based studies (Testa, 2017).

Building Type	Cooling energy saving [%]	Heating penalties [%]
Old residential	4-11	0-2
New residential	1-8	0-2
Old office building	4-8	0-3
New office building	2-4	0-6
Old retail stores	6-11	0-6
New retail stores	4-7	0-10

From the reported results, it can be noted that a white cool roof can provide cooling energy savings but heating energy penalties can occur. Moreover, old buildings present better gains in general. Hence, the white roof solar reflection has more impact on the buildings that are less insulated. Indeed, micro-cracks appear on the roofs over time, especially when the roofs are not regularly maintained. This leads to an increase in thermal bridge effects. That is why, a retrofitting white coating solution can, on the one hand, reflect more but also can prevent thermal bridges to appear by covering the micro-cracks.

Similar results have been obtained in the field studies. Konopacki et al. concluded that white roofs present energy savings during the year for residential and commercial buildings. (Konopacki, et al., 2001). Moreover, they established that residential buildings can have some advantages with respect to commercial ones in the warmest localities.

THE EXPLORATION THROUGH INNOVATION 4 CHANGE

The experiment described in this manuscript took place in the Innovation for Change (I4C), a program that is collaboration between Collège des Ingénieurs, Politecnico di Torino and CERN. I4C is structured through 20 days of workshops spread over a period of 20 weeks during each group must come up with a prototype. During these 20 weeks, the participants follow an entrepreneurship and innovation journey based on scientific approach and design thinking methodology.

In the I4C program, collaboration and interdisciplinary within and around the team are necessary conditions for boosting innovation and having a positive impact on society. The program ends with the Demo Day which represents an opportunity for the teams to showcase their prototypes and possibly convince potential investors and bring innovation to the market. In the following section, the prototyping experience that has taken place during the second visit at CERN IdeaSquare will be explained.

PROTOTYPING

The goal of this experiment is to have tangible proof of the effect of the roof color in a close-environment temperature. The experiment was conducted under clear sky condition in the time window between h 12:00 and 15:00 of the 16th of May 2019 during the second visit at CERN in Geneva (lat: 46.23°; long: 6.05°). The external temperature was constant during the entire duration of the experiment at 33 °C, measured by a thermocouple with an accuracy of 0.1°C. The Prototype has a dimension of 35x40x40 cm. The facades are composed by a 5 cm fiberglass insulating material (Thermal conductivity Index 0.032 [W/mK]), while the roof is made of a 0.5 cm polycarbonate layer having the antipodal surfaces of light blue and brilliant white respectively (see Fig. 1). The relatively high insulation of the facade permits to reduce any parasitic effect in the temperature changing such as wind by minimizing wall heat transfers. Therefore, it results in highlighting the effect of the roof color only.

The prototype was positioned under the sunlight, firstly with the light blue roof. The initial temperature inside the prototype (T_0) was measured and equal to the ambient temperature of 33°C. After a thermal transient of 20 minutes, the final temperature (T_F) has reached the value of 40°C.

Fig.1 The experiment carried out at CERN Idea Square.

Tab. 3. Experimental results

Roof Color	[lx]	Albedo Index	T_0 [°C]	T_F [°C]
Light Blue	212738	0.44	33	40
White	372300	0.80	33	38

Finally, the white roof was applied. In this case, the final temperature, after the thermal transient was 38°C. The measurements have been repeated several times and no changes in the result have been noticed with the used instrument. The solar fraction reflected, albedo index, by the two different colors was measured by a specific mobile application; the results are reported in Table 3. In order to provide a better understanding of this result, we may consider that the cooling energy spent (Q) is directly proportional to the delta T.

$$Q = \rho V c \Delta T \quad (1)$$

where, ρ (mass density of the air), V (Volume of air inside) and c (heat mass capacity of the air) are constants by changing the color of the roof. Assuming 20°C as standard temperature according to the Italian regulation in commercial and office buildings it follows that

$$\frac{(\Delta Tblue - \Delta Twhite)}{\Delta Tblue} = \frac{(Qblue - Qwhite)}{Qblue} = 10\%. \quad (2)$$

To conclude, our experimentation showed a 10% cooling energy saving by changing from light blue to white polycarbonate roof in a highly insulated façade-based prototype.

SIMULATION

To support the results obtained, starting from the prototyping experiment realized at CERN IdeaSquare, a computer-based simulation has been done with the EnergyPlus™ software. EnergyPlus™ is an entire building energy simulation program that is used to simulate the energy consumption both for heating and cooling. The simulation aims to compare the building thermal behavior with a dark roof and a white roof over a year and their respective energy consumption. The simulation was launched for a single-story office building situated in the city of Turin in Italy first with a dark roof, and then with a white-coated roof. One-year meteorological data was set into the program as one of the two inputs. The other input is the geometry of the single-story office building. The parameters of the dark roof were fixed as follows:

- Thermal absorptance = 0.9
- Visible absorptance = 0.9
- Solar absorptance = 0.9

- Thickness (m) = 0.01
- Specific Heat (J/kgK) = 1460
- Density (kg/m3) = 1121.3
- Conductivity (W/mK) = 0.16

The parameters of the roof with white roof were fixed as follows:

- Thermal absorptance = 0.2
- Visible absorptance = 0.2
- Solar absorptance = 0.2
- Thickness (m) = 0.01

The results of the simulation are shown in Fig. 2 and Fig.3. Fig.2 reports the roof temperature behavior during the year without white coating (orange curve) and with the white coating (blue curve). From the graph, it can be easily seen that the white roof presents a lower temperature variation.

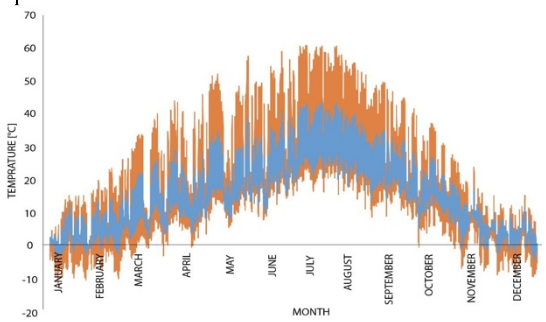

Fig. 2. Roof surface temperature comparison with (blue curve) and without (orange curve) the white coating over a year.

However, this difference is higher in the warm seasons with difference ranges up to 20°C, while difference is more moderate in winter as the roof temperature differ with only some degrees. This is because during winter, the roof is less exposed to the solar radiation. Therefore, the roof color becomes less impactful parameter on its temperature.

Fig.3 shows the aggregate energy spent on heating and cooling during the year with or without white coating. As it can be observed, in the case of white roofs, the heating energy demand is higher compared to the one obtained for the dark roof.

In particular, 7% of energy penalties were found during a year. However, on the other hand, the reduction in cooling needs due to the improved reflectivity of the roof leads to 17% of energy savings. The net total savings, therefore, lies in the order of 10% with an absolute value for the simulated case around 1000 kWh saved per year.

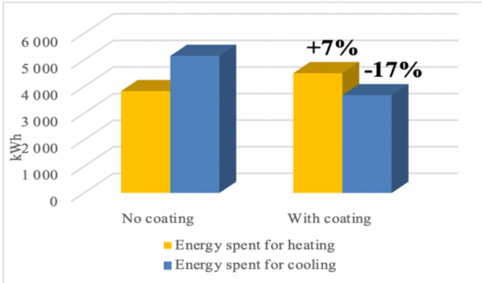

Fig. 3. Total energy consumption comparison between "No coating" and "With coating" scenarios.

DISCUSSION AND CONCLUSIONS

This work has explored the potential of white roofs as an effective solution to address global warming, urban heat island effect and energy consumption in buildings. In particular, if this solution would be spread worldwide in all cities, it could reach the targeted white reflective surface to annihilate the global warming effect. At the building scale, we find that it can lead to 10% of energy savings of the heating and cooling demand over a year. This retrofitting white roof coating solution provides better results for old buildings with less insulation and in warm regions with a higher cooling need. The future of this project lies in the application of numerical simulations to quantify its benefits regarding energy savings for heating and cooling for different climate regions based on a comparative approach along with a sensitivity analysis.

In addition, a deeper study in materials able to have both a high reflective index, as Poly-Sil White, and a lower thermal conductivity coefficient, such as silica aerogels, should be conducted. Furthermore, the roof insulating and life span increasing benefits by recovering the micro-cracks should be further investigated. These could represent new experiments in IdeaSquare or similar experimental innovation lab. Finally, the material research and development of thermochromic paints, able to become white with high temperatures could overcome not only the issue of historical heritage and city's roof landscape conservation, but also remove the heating penalties in winter by recovering its original color and initial absorptance properties.

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REFERENCES

Akbari H, Bretz S, Kurn D, Haniford J., 1997. Peak power and cooling energy savings of high-albedo roofs, Energy Build 25: pp. 117–26.

Akbari H, Konopacki S., 2005. Calculating energy-saving potentials of heat-island reduction strategies, Energy Policy 33: pp. 721–56.

Akbari H, Levinson R, Rainer L., 2005. Monitoring the energy-use effects of cool roofs on California commercial buildings, Energy Build 37: pp. 1007–101.

Altan H. Alshikh Z., Belpoliti V, Ki Kim Y, Said Z. Al-Chaderchi M., 2019. "An experimental study of the impact of cool roof on solar PV electricity generations on building rooftops in Sharjah, UAE" International Journal of Low-Carbon Technologies, 14(2): pp. 267–276.

Boucher, O., D. Randall, P. Artaxo, C. Bretherton, G. Feingold, P. Forster, V.-M. Kerminen, Y. Kondo, H. Liao, U. Lohmann, P. Rasch, S.K. Satheesh, S. Sherwood, B. Stevens, and X.Y. Zhang, 2013: Clouds and aerosols. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Doschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, Eds. Cambridge University Press, pp. 571-657.

Bretz, S.E, Akbari, H., 1997. Long-term performance of high-albedo roof coatings. Energy and Buildings 25(2): pp. 159-167

Cubi, E., Zibin, N. F., Thompson, S. J., Bergerson, J., 2015. Sustainability of rooftop technologies in cold climates: Comparative life cycle assessment of white roofs, green roofs, and photovoltaic panels, Journal of Industrial Ecology, 20(2): pp. 249-262.

Grinsted, A., Moore, J.C., Jevrejeva, S., 2013. Reply to Kennedy et al.: Katrina storm records in tide gauges, Proc. Natl. Acad. Sci. 110: pp. 2667.

Heat Island Group, Berkley Lab, https://heatisland.lbl.gov

Keller, D.P., Feng, E.Y., Oschlies, A., 2014. Potential climate engineering effectiveness and side effects during a high carbon dioxide-emission scenario, Nature Communications 5, 3304.

Konopacki S, Akbari H, Gartland L, Rainer L., 1998. Demonstration of energy savings of cool roofs, Berkeley (CA): Lawrence Berkeley National Laboratory, Report numberLBNL-40673

Konopacki S, Akbari H., 2001. Measured energy savings and demand reduction from a reflective roof membrane on a large retail store in Austin, Berkeley (CA): Lawrence Berkeley National Laboratory, Report number LBNL-47149.

Levinson, R. & Akbari, H., 2010. Potential benefits of cool roofs on commercial buildings: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants, Energy Efficiency 3(1): pp. 53– 109.

Mannshardt, E., Gilleland, E., 2013. Extremes of severe storm environments under a changing climate. Am. J. Clim. Change 2: pp. 47-61.

Moore, J.C., Grinsted, A., Zwinger, T., Jevrejeva, S., 2013. Semi-empirical and process based global sea level projections, Reviews of Geophysics 51: pp. 484-522.

Moore, J.C., Jevrejeva, S., Grinsted, A., 2011. The historical global sea level budget, The Annals of Glaciology 52: pp. 8-14.

Niemeier, U., Schmidt, H., Alterskjær, K., Kristjansson, J.E., 2013. Solar irradiance reduction via climate engineering impact of different techniques on the energy balance and the hydrological cycle, Journal of Geophysical Research. 118, pp. 11905-11917.

Oleson, K. W., Bonan, G.B., Feddema, J., 2010. Effects of white roofs on urban temperature in a global climate model. Geophysical Research Letters, 37(3).

Parker D, Huang J, Konopacki S, Gartland L, Sherwin J, Gu L., 1998. Measured and simulated performance of reflective roofing systems in residential buildings, ASHRAE Trans 104: pp.963–75.

Parker D, Sonne J, Sherwin J., 1997. Demonstration of cooling savings of light-colored roof surfacing in Florida commercial buildings: retail strip mall, Cocoa (FL): Florida Solar Energy Center, Report FSEC-CR-964-97.

Princiotta, F.T., 2011. Global Climate Change - The Technology Challenge, Springer Netherlands

Schaltegger, S., Csutora, M., Huisingh, D., 2011. Climate costs and benefits: new challenges for corporate accounting and management. J. Clean. Prod. 19: pp. 1141-1143.

Scherba, A., Sailor, D.J., Rosenstiel, T.D., Wamser C. C., 2011. Modeling impacts of roof reflectivity, integrated photovoltaic panels and green roof systems on sensible heat flux into the urban environment, Building and Environment, 46: pp. 2542-2551.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, 2007, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Strauss, F., Moltchanova, E., Schmid, E., 2013. Spatially explicit modeling of long term drought impacts on crop production in Austria, American Journal of Climate Change 2 (3A): pp. 1-11.

Testa, J. & Krarti M, 2017. A review of benefit and limitation of static and switchable cool roof, Renewable and Sustainable Energy reviews 77: pp. 451-460.

The NYC Construction Codes, General Administrative Provisions, Building Code, 2008, https://www1.nyc.gov/assets/buildings/apps/pdf_viewer/viewer.html?file=2008CC_BC_Chapter_15_Roof_Assemblies_and_Rooftop_Structures.pdf&section=conscode_200

United Nations Report, 2018, https://news.un.org/fr/story/2018/05/1014202

Urban, B. & Roth, K., 2010. Guidelines for selecting cool roofs. Washington, DC: U.S. Department of Energy, Building Technologies Program.

World Bank Report, 2008, https://www.worldbank.org/en/news/press-release/2018/03/19/climate-change-could-force-over-140-million-to-migrate-within-countries-by-2050-world-bank-report>