European Geosciences Union General Assembly 2019
Vienna, Austria, 7-12 April 2019
HS7.4/CL2.29/NP3.7 - Hydroclimatic change and unchange: exploring the mysteries of variability, nature and human impact (co-sponsored by IAHS, and WMO CHy) (co-organized)

Stochastic similarities between natural processes and art: Application in the analysis and optimization of landscape aesthetics of renewable energy and civil works

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Abstract

Stochastics help develop a unified perception of natural phenomena and expel dichotomies like random vs. deterministic, as both randomness and predictability coexist and are intrinsic to natural systems. A natural system can be deterministic and random at the same time, depending on the prediction horizon and the time scale. The high complexity and uncertainty of natural processes has long been identified through observations as well as extended analyses of hydrometeorological processes such as temperature, humidity, surface wind, precipitation, atmospheric pressure, river discharges etc. All these processes seem to exhibit high unpredictability due to the clustering of events.

Art is usually not considered a natural process, but other than a mix of determinism (e.g., certain rules have to be followed) it also includes stochasticity (e.g., creativity and inspiration). A stochastic analysis of works of art allows for the identification of the existence of possible intrinsic uncertainty. This analysis includes the investigation of Hurst-Kolmogorov behavior in the art of different historical periods (visual arts, music and poetry) and of similarities with natural processes. Based on the stochastic analysis of artworks, a method of image analysis is developed that is applied in analyzing the landscape impact in cases of insertion of architectural elements in the natural landscape, formulating an indicator that can be used for analyzing the impact of works of engineering on the landscape.

1. Introduction - Art and mathematics

Art is inherent in the evolution of human civilization. Since the beginning of civilization, human minds have been embodying their creativity into different forms of arts, ranging from prehistoric cave paintings to the various forms of contemporary art. These works of art have been creating feelings, through their aesthetics, and disseminating ideas and messages, underlying of upfront, through their communication with the intellect. In different stages of history, art has even been in the frontline of the struggle of human civilizations for progress, expressing social and political ideas that were far from being implemented in the societies of those times.

The analysis of the connection between the artist and the recipient of art has always been of high interest in both philosophy and science. Even though this analysis has mostly been considered part of the so-called social studies and humanities, mathematicians have also been involved. Mathematicians are generally not specialized to contribute, through their expertise, in sociopolitical analysis of messages and motivations of art but have been consistently applying mathematical knowledge, which is their expertise, in trying to explain aesthetics. In most of these analyses, the question at hand, is if what is pleasing/ or not pleasing to the eye can be explained though mathematics.

Historically, it is known that from the time of the ancient Egyptian civilization a mathematic rule of the analogies of human body had been developed [1], and later in ancient Greece, the mathematicians Pythagoras and Euclid [2] were the first known to have searched for a common rule (canon) existing in shapes that are perceived as beautiful. Euclid's Elements (c. 300 BC), for example, contains the first known definition of the "golden ratio":

A straight line is said to have been cut in extreme and mean ratio when, as the whole line is to the greater segment, so is the greater to the lesser.

Conversely, the view of philosophers such as Aristotle, that "art takes nature as its model" and "art not only imitates nature, but also completes its deficiencies" seem to suggest that expression through art is above any natural rules that could be described by with mathematical modeling [3]. Similarly, Plato connected his aesthetic theory, as well, mostly with ideas, the soul and idealistic expression [4].

The opinions of later philosophers on this pursuit of mathematicians in the analysis of aesthetics were more varied. Leibniz, for example, believed that there is a norm behind every aesthetic feeling which we simply don't know how to measure. Rene Descartes, on the contrary, supports that instead of regarding the aesthetic quality as an inherent quality of a physical object, the distinction of mind and nature have allowed humans to incorporate their own subjective feelings in determining their aesthetic preferences.

In this particular application of mathematical methods in the analysis of arts and aesthetics, a new logic is promoted, based on which art and aesthetics are not treated neither as strictly deterministic nor as being completely unable to be described by rules of mathematics. Aesthetics and art are treated similarly to how natural processes are treated in the context of a stochastic analysis, and an attempt is made to identify the degree of their intrinsic uncertainty. After successfully identifying a stochastic Hurst – Kolmogorov (HK) in arts of different historical periods, a similar investigation is made into different landscapes produced by different renewable energy (RE) technologies.

2. Incorporating stochastic analysis in arts and landscape aesthetics

Stochastic calculus helps in developing a unified perception of natural phenomena and expel dichotomies like random vs. deterministic. It seems that rather both randomness and predictability coexist and are intrinsic to natural systems which can be deterministic and random at the same time, depending on the prediction horizon and the time scale [5].

The high complexity and uncertainty of natural processes has long been identified through plain observations as well as extended analyses of hydrometeorological processes such as temperature, humidity, surface wind, precipitation, atmospheric pressure, river discharges etc[6]. Particularly, all these processes seem to exhibit high unpredictability due to the clustering of events.

On the other hand, art is expected to be a mix of determinism (e.g., certain rules have to be followed) and stochasticity (e.g., creativity and inspiration). In this analysis, initially, an attempt is made to identify the degree of intrinsic uncertainty in paintings of different periods and present an evaluation of a possible Hurst-Kolmogorov behavior, using stochastic analysis. Subsequently, the method of image processing developed for the analysis of art is also applied in the analysis of photographs of renewable energy installations and civil works on the landscape, to investigate differences between major RE technologies. Finally, through the analysis of various images of landscapes (natural landscapes, renewable energy landscapes and urban landscapes), a preliminary version of a tool for the evaluation of the aesthetic impact of human interventions on landscapes is developed.

3. Uncertainty and scale

The behavior of some processes to exhibit high unpredictability due to the clustering of events was first identified in Nature by H.E. Hurst in 1951 while working at the River Nile, although its mathematical description and further analysis of this behavior is attributed to A. N. Kolmogorov who developed it while studying turbulence in 1940. Later, D. Koutsoyiannis [7] named this behavior as Hurst-Kolmogorov (HK). The high uncertainty of climate dynamics has been linked to the power-law type of both the marginal distribution and the dependence structure through empirical evidence [8] as well as theoretical justification [9].

The dependence structure of a process is represented by the (second-order) climacogram, i.e., the variance of the averaged process vs. scale k, where k = κD is the continuous-time scale in time units and κ the dimensionless discrete one, assuming that D is a time unit that is used for discretization. Although the climacogram is directly linked to the autocovariance and power spectrum (i.e., each of these three stochastic tools contains exactly the same information [10], it has been shown that the climacogram provides better estimates than the other two [11].

4. Methodology - Application in analysis of paintings

Stochastic analysis in 2d

For the analysis of landscapes, through photographs, the methodology used is based on the methodology previously developed for the analysis of paintings [12]. Each painting is digitized is 2d based on a grayscale color intensity and the climacogram is calculated based on the geometric scales of adjacent pixels [13]:

$$s = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

In more depth about the methodology of the climacogram for 2d processes, assuming that our sample is an area nΔ × nΔ, where n is the number of intervals (e.g. pixels) along each spatial direction and Δ is the discretization unit (determined by the image resolution, e.g. pixel length), the empirical classical estimator of the climacogram for a 2d process can be expressed as:

$$\underline{\hat{\gamma}}(\kappa_1, \kappa_2) = \frac{1}{n^2/\kappa^2 - 1}\sum_{i=1}^{n/\kappa_1}\sum_{j=1}^{n/\kappa_2}\left(\underline{x}_{i,j}^{(\kappa)} - \underline{\bar{x}}\right)^2 \tag{1}$$

where the "^" over γ denotes estimation, $\kappa := \sqrt{\kappa_1 \kappa_2}$ is the geometric mean of the discrete scales κ_1, κ_2, with $\kappa_1 = k_1/\Delta$ and $\kappa_2 = k_2/\Delta$ the dimensionless spatial scales, $\underline{x}_{i,j}^{(\kappa)} = \frac{1}{\kappa^2}\sum_{\psi=\kappa_1(j-1)+1}^{\kappa_1 j}\sum_{\xi=\kappa_2(i-1)+1}^{\kappa_2 i}\underline{x}_{\xi,\psi}$ is the sample average of the space-averaged process at scale κ, and $\underline{\bar{x}} = \sum_{i,j=1}^{n}\underline{x}_{i,j}/n^2$ is the sample average. Note that the maximum available scale for this estimator is n/2.

A variety of processes exhibit LTP behaviour (e.g. Dimitriadis, 2017), the simplest one being the isotropic Hurst-Kolmogorov (HK) process, i.e. power-law decay of variance as a function of scale, and defined for a 1d or 2d process as:

$$\gamma(k) = \frac{\lambda}{(k/\Delta)^{2d(1-H)}} \tag{2}$$

where λ is the variance at scale k = κΔ ($k_1 = k_2 = \kappa\Delta$), d is the dimension of the process/field (i.e., for a 1d process d = 1, for a 2d field d = 2, etc.), and H is the Hurst parameter (0 < H < 1).

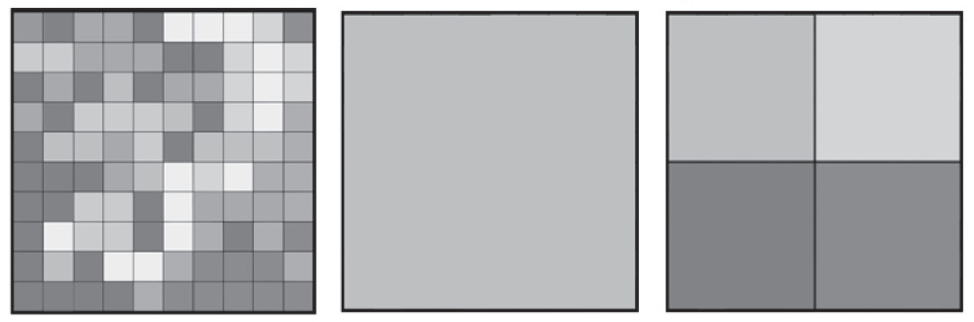

Figure 1: (a) Example of pixels in 2d picture, (b) the average of pixels and (c) grouped pixels (scales) used to calculate the climacogram.

The pixels analysed are actually represented by numbers based on their grayscale color intensity. An example of climacograms generated by data sets with different statistical characteristics is presented in fig. 2 and fig.3.

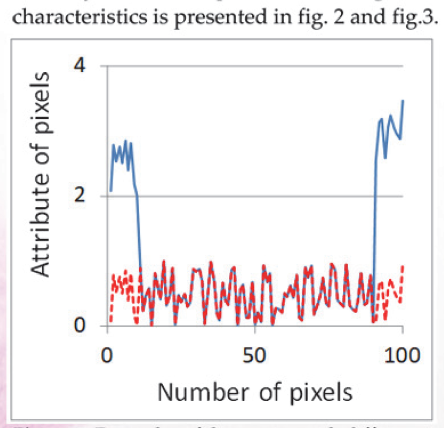

Figure 2: Examples of data series with different statistical characteristics in 1 dimension

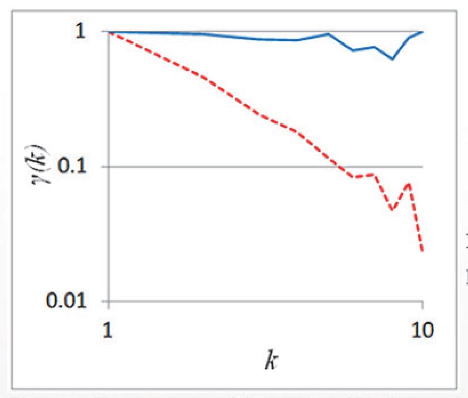

Figure 3: Climacograms of data series of Fig.2

5. Application in analysis of landscapes.

The unexpected importance of the aesthetics of renewable energy

Globally, the scale of the transformation caused to landscapes from Renewable Energy (RE) developments is larger than ever. Indicatively, in countries with high wind energy utilization rates, the percentage of land area in which wind turbines are clearly visible is 18% in Spain [14], 21% the Netherlands [15] and even 46% in Scotland [16] and regarding solar panels the percentage is 4.8%, in the only national-scale study, to date, with data from Spain [14]. These studies demonstrate the scale of the visual intrusion of wind and solar energy into landscapes and justify why strong opposition on visual-impact grounds has emerged against RE projects. This friction, between renewable energy and landscape has consistently been the cause of delays in the development of renewable energy projects and has raised the issue of landscape management in Europe [17] and globally.

Some basic contributors to the generation of significant visual impact from RE projects are the large requirements of land use, more evident in the case of solar energy [18, 19], as well as the great dispersion of facilities and equipment, that is characteristic of wind energy [20]. However, these characteristics are also present, to an extent, in hydroelectric projects, which in contrast to wind and solar developments have not been opposed significantly, from a landscape-impact perspective, even though hydroelectricity is the type of renewable energy with the highest installed capacity globally [21]. One important aesthetic difference between solar and wind developments on the one hand and hydroelectric developments on the other hand, is that hydroelectricity produces a new landscape which is to a great degree natural-like. The hydroelectric landscape mainly consists of an artificial lake – a reservoir, in contrast to wind and solar developments, in which the new landscapes developed are dominated, visually, by human-made industrial equipment. Thus, wind and solar energy projects have been significantly critiqued on industrializing landscapes.

To mitigate this industrial intrusion and facilitate the expansion of RE, several different methods have been developed to quantify and evaluate visual impact from renewable energy, ranging from photomontage and digital representation to GIS viewshed analyses [22]. In these methods the basic parameters that are considered determinant of this impact are: viewing distance, atmospheric clarity, color contrast with background, movement of wind turbine blades and perception from individuals [23]. They are used mostly to optimize the sitting of a new RE project or to evaluate its landscape impact in the form of an environmental impact analysis.

In this paper, the application of a stochastic analysis is combined with elements from these methods in analyzing landscapes created by utilizing different types of RE technologies. The paper aspires to determine whether the industrialization of landscapes, caused by solar and wind is somehow expressed in mathematical terms and how this might be related to the visual impact of hydroelectric projects.

Landscape analysis

In order to analyze the transformation produced by RE technologies to landscapes, photographs with views of natural and man-made landscapes were used (fig.4, fig.6 and fig.8). The landscapes selected were natural landscapes suitable for the installation of renewable energy projects, landscapes where renewable energy projects have already been installed and finally some urban landscapes to be used as means of comparison of 100% natural to 100% man-made landscapes, in the discussion.

Image processing typically involves filtering or enhancing an image using various types of functions in addition to other techniques to extract information from the images [24]. Image segmentation is one of the basic problems in image analysis. The importance and utility of image segmentation has resulted in extensive research and numerous proposed approaches based on intensity, color, texture, etc, and both automatic and interactive [25]. A variety of techniques have been proposed for the quantitative evaluation of segmentation methods [26], [27], [28].

In this analysis the methodology which was originally developed for the analysis of paintings is used, as described in chapters 3 and 4. As similar behavior was found in the cllimacograms of similar landscapes (similar behavior in the climacograms from the analysis of pictures of forest landscapes, similar behavior in the climacograms from the analysis of pictures of lake and reservoir landscapes, etc.), the climacograms generated were considered representative of the respective type of landscape (fig 5., fig7 and fig. 9). The climacograms of fig. 5 and fig. 7, were formed using the averages of multiple pictures for each type of landscape, i.e. the pictures of fig. 4 and fig.6, while the climacogram of fig.9 was formed using one picture for each type of landscape, i.e. the pitcures of fig.8.

Figure 4. Images processed for the calculation of the climacograms of figure 5 (natural landscapes, reservoir and lake landscapes, photovoltaic energy landscapes and wind energy landscapes).

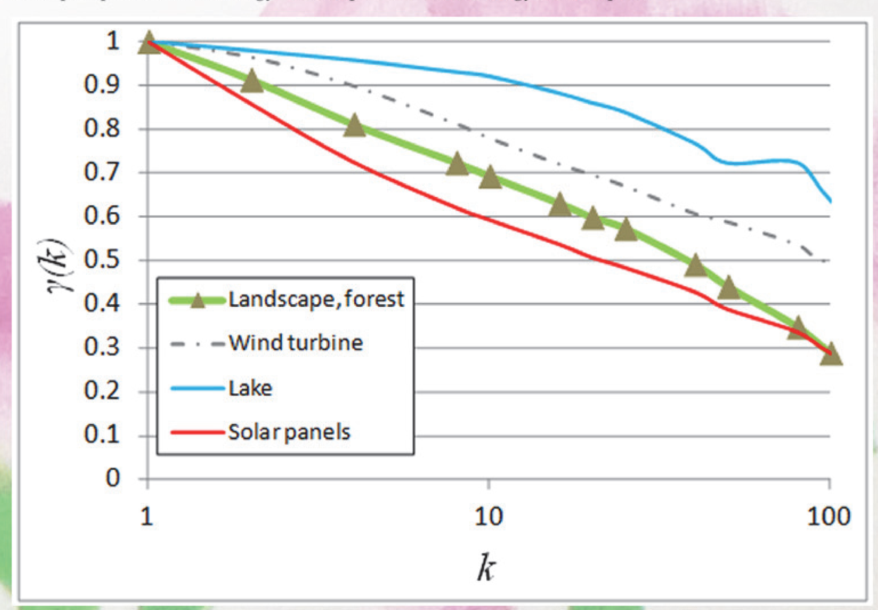

Figure 5: Climacograms of each type of examined landscape, using for the average climacograms of pictures of fig. 4 (natural landscapes, reservoir and lake landscapes, photovoltaic energy landscapes and wind energy landscapes)

Figure 6. Additional images processed for the calculation of the climacograms of figure 7

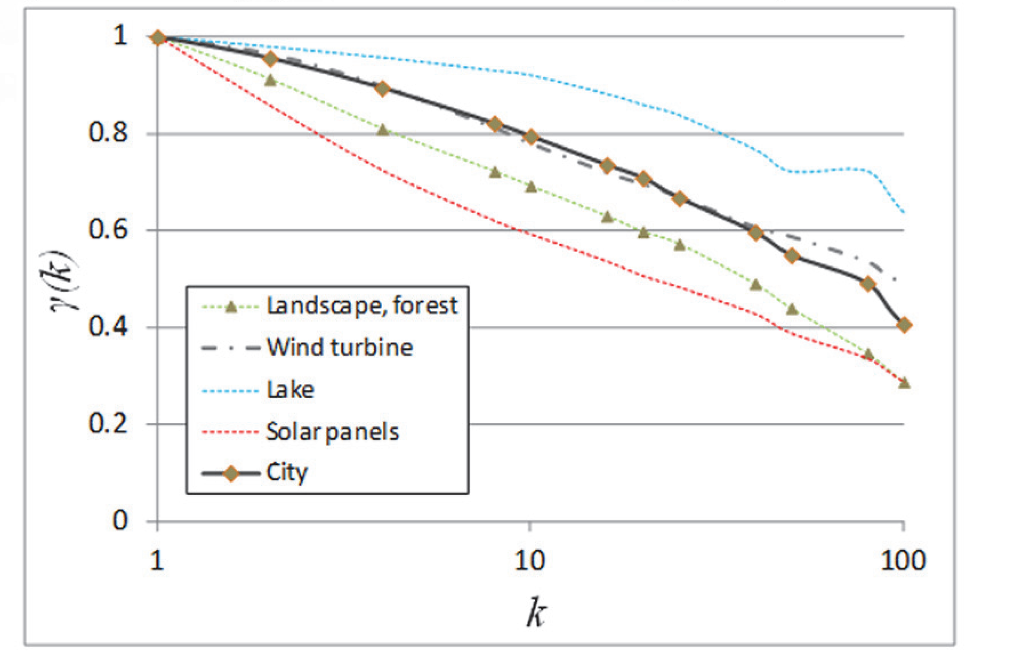

Figure 7. Average climacograms for each type of examined landscape using the pictures of fig. 4 and fig.6 (natural landscapes, reservoir and lake landscapes, photovoltaic energy landscapes and wind energy landscapes and urban landscapes

In order to achieve a better understanding of the effect of the transformations from renewable energy on landscape, the following digitally processed image was analysed (Figure 8). The number of pixels transformed is equal in the two images of a section of a reservoir and a section of a photovoltaic project.

Figure 8. Images processed for the climacogram of figure 9 (natural landscape, hydroelectric reservoir landscape and photovoltaic project landscape).

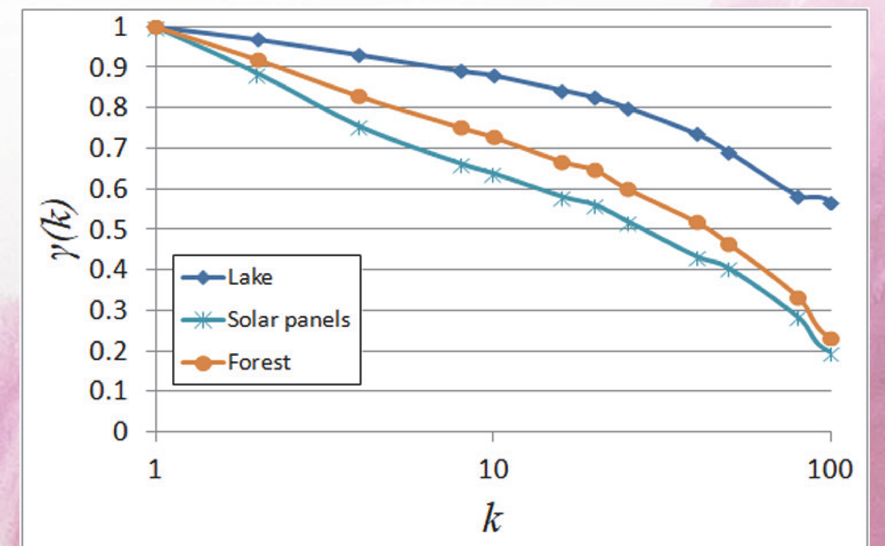

Figure 9. Climacograms of examined landscapes of fig.8 (natural landscape, hydroelectric reservoir landscape and photovoltaic project landscape

In fig. 9 it is observed that the landscape after the digital insertion of pixels of an image of alake demonstrates intense contrasts which are quantified in the climacogram, while the photovoltaics tend to homogenize the climacogram.

6. Conclusions

- The natural landscape of a forest, demonstrates a typical curve (without great dispersion regardless of image)
- The natural landscape is "flattened" with photovoltaics (loses its complexity), which is demonstrated by the scales in the climacogram.
- The lake increases contrast in the landscape and presents increased clustering
- Wind turbines (usually sited on ridges or plains) increase the contrast of the landscape and its complexity overall. In climacograms produced in the analyzes made, as interesting observation is that the scales of wind turbine landscapes coincide with the scales of urban landscapes, which also demonstrate visual heterogeneity. In conclusion, transformations created to natural landscapes by wind turbines exhibit the greatest similarity to urban landscape transformations, so, arguably, wind turbines seem to urbanize/industrialize natural landscapes.

References

1 The Art of Ancient EGYPT, A RESOURCE FOR EDUCATORS, The Metropolitan Museum of Art, New York: The Metropolitan Museum of Art. p. 44. Retrieved July 7, 2013.

2 Robin Allott, The Pythagorean Perspective:The Arts and Sociobiology, Journal of Social and Evolutionary Systems 17(1):71-90, JAI PISS, Inc.,1994.

3 Αριστοτέλης, Ποιητική 1447a, 19-23.

4 Tatarkiewicz, W., 1970. History of Aesthetics, The Hague, Mouton, sect. A, p. 113.

5 Dimitriadis, P., Koutsoyiannis, D., Tzouka, K., 2016. Predictability in dice motion: how does it differ from hydro-meteorological processes? Hydrol. Sci. J. 61, 1611–1622.

6 Dimitriadis, P., 2017. Hurst-Kolmogorov dynamics in hydrometeorological processes and in the microscale of turbulence, PhD thesis, Department of Water Resources and Environmental Engineering – National Technical University of Athens.

7 Koutsoyiannis, D., 2010. HESS Opinions "A random walk on water". Hydrol. Earth Syst. Sci., 14, 585–601.

8 Newman, M.E.J., 2005. Power laws, pareto distributions and zipf's law, Contemporary Physics, 46:323–351.

9 Koutsoyiannis, D., 2011. Hurst–Kolmogorov dynamics as a result of extremal entropy production. Phys. Stat. Mech. Its Appl. 390, 1424–1432.

10 Koutsoyiannis, D., 2016. Generic and parsimonious stochastic modelling for hydrology and beyond. Hydrol. Sci. J. 61, 225–244

11 Dimitriadis, P., Koutsoyiannis, D., 2015a. Climacogram versus autocovariance and power spectrum in stochastic modelling for Markovian and Hurst–Kolmogorov processes. Stoch. Environ. Res. Risk Assess., 29, 1649–1669.

12 G.-F. Sargentis, P. Dimitriadis, T. Iliopoulou, R. Ioannidis, and D. Koutsoyiannis, Stochastic investigation of the Hurst-Kolmogorov behaviour in arts, European Geosciences Union General Assembly 2018, Geophysical Research Abstracts, Vol. 20, Vienna, EGU2018-17740-1, European Geosciences Union, 2018.

13 Tyralis, H., P Dimitriadis, D Koutsoyiannis, P.E. O'Connell, K. Tzouka, and T. Iliopoulou, 2017. On the long-range dependence properties of annual precipitation using a global network of instrumental measurements, Advances in Water Resources, 111, 301-318.

14 Rodrigues M, Montañés C, Fueyo N (2010) A method for the assessment of the visual impact caused by the large-scale deployment of renewable-energy facilities. Environmental Impact Assessment Review 30:240–246.

15 CBS, PBL, RIVM, WUR (2014) Visual disturbance of landscape amenity by wind turbines.

16 SNH (2014) Natural Heritage Indicator - N3 Visual influence of built development.

17 Prof. Dr. Christina v. Haaren, Carolin Galler, Stefan Ott, Landscape planning The basis of sustainable landscape development, German Federal Agency for Nature Conservation, edt. Gebr. Klingenberg Buchkunst Leipzig GmbH, 2008

18 Ong S, Campbell C, Denholm P, Margolis R, Heath G (2013) Land-use requirements for solar power plants in the United States. National Renewable Energy Laboratory Golden, CO.

19 Trainor AM, McDonald RI, Fargione J (2016) Energy Sprawl Is the Largest Driver of Land Use Change in United States. PLOS ONE 11:e0162269. doi: 10.1371/journal.pone.0162269.

20 Denholm P, Hand M, Jackson M, Ong S (2009) Land-use requirements of modern wind power plants in the United States. Golden, CO: National Renewable Energy Laboratory 57

21 WEC (2016) Word Energy Resources Hydropower 2016

22 Landscape Institute, I.E.M.A. (2013) Guidelines for Landscape and Visual Impact Assessment. London: Routledge.

23 Buchan N (2002) Visual Assessment of windfarms: Best practice. Scottish Natural Heritage Commissioned Report F01AA303A Callaghan: University of Newcastle

24 Hui Zhang, Hui Zhang, Jason E. Fritts, Jason E. Fritts, Sally A. Goldman, Sally A. Goldman, } "An entropy-based objective evaluation method for image segmentation", Proc. SPIE 5307, Storage and Retrieval Methods and Applications for Multimedia 2004, (18 December 2003); doi: 10.1117/12.527167; https://doi.org/10.1117/12.527167

25 Martin D., Fowlkes C., Tal D., Malik J. (2001)."A database of human segmented natural images and its application to evaluating algorithms and measuring ecological statistics". ICCV, 416–423

26 Kohonen T., "Self-Organizing Maps", 2nd edition, Springer-Verlag, Heidelberg, 1997.

27 I.E. Abdou, W.K. Pratt, "Quantitative design and evaluation of enhancement/thresholding edge detector," in Proceeding of IEEE, 67(5), May 1979. 2.
William A. Yansnoff and Jack K. Mui, "Error Measure for scene segmentation," Pattern Recognition, 9, pp. 217–231, 1977.

28 P.K. Sahoo, S. Soltani, A.K.C. Wong, and Y.C. Chen, "Survey: A survey of thresholding techniques," Computer vision, Graphics and Image Processing, 41, pp. 233–260 1988. 4.
Martin D. Levine and Ahmed M. Nazif, "Dynamic Measurement of Computer Generated Image Segmentations," IEEE Transaction on Pattern Analysis and Machine Intelligence, 7(2), pp. 155–164, 1985. 5.
Nikhil R. Pal and Sankar K.Pal, "A Review on Image Segmentation Techniques,"Pattern Recognition, 26(9), pp. 1277–1294 1993. 6. J.S. Weszka and A. Rosenfeld, "Threshold evaluation techniques," IEEE Trans, System Man Cybernet, 8(8), pp. 622–629, 1978. 7.
N. Otsu, "A threshold selection method from gray-level histograms," IEEE Trans. Syst., Man, Cybern., 9(1), pp. 62–66, 1979.

Drawing of poster's background: Eleni -Angelina Sargenti-Kougia

Acknowledgments: This research has been supported by the OptArch project: "Optimization Driven Architectural Design of Structures" (No: 689983) belonging to the Marie Skłodowska-Curie Actions (MSCA) Research and Innovation Staff Exchange (RISE) H2020-MSCA-RISE-2015.