Master Thesis in Geographical Information Science nr 71

Quantitative model of Present and Future well-being in the EU-28: A spatial Multi-Criteria Evaluation of socioeconomic and climatic comfort factors

Joakim Jörwall

2017

Department of
Physical Geography and Ecosystem Science
Centre for Geographical Information Systems
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

Joakim Jörwall (2017). *Quantitative model of Present and Future well-being in the EU-28: A spatial Multi-Criteria Evaluation of socioeconomic and climatic comfort factors*
Master degree thesis, 30 credits in Master in Geographical Information Sciences
Department of Physical Geography and Ecosystem Science, Lund University

Level: Master of Science (MSc)

Course duration: *September* 2016 until *January* 2017

Cover photo: Autumn fields in southern Sweden (courtesy of Patricia Patten Jörwall).

Quantitative model of Present and Future well-being in the EU-28: A spatial Multi-Criteria Evaluation of socioeconomic and climatic comfort factors

---

Joakim Jörwall

Master thesis, 30 credits, in Geographical Information Sciences

Advisor:
Dr. Micael Runnström
Department of Physical Geography and Ecosystem Science

Exam committee:

Dr. Vaughan Phillips
Department of Physical Geography and Ecosystem Science

Prof. David Tenenbaum
Department of Physical Geography and Ecosystem Science

Acknowledgements

I am very grateful to my advisor Dr. Micael Runnström for his insightful and helpful comments and suggestions, pointing me in the right direction and challenging me to do my very best.

I would also like to thank Ian Harris of the Climatic Research Unit (CRU) at the University of East Anglia, for generously providing me with the necessary climatology data.

Finally, I would like to dedicate this work to my dear wife Patricia; without her boundless love, patience, and support it would not have been possible for me to get started on, let alone finish, my thesis.

Joakim Jörwall

Abstract

Quantitative model of Present and Future well-being in the EU-28: A spatial Multi-Criteria Evaluation of socioeconomic and climatic comfort factors

Both within the EU and within other regions/countries, there is a need to measure and monitor the well-being/Quality of Life (QoL) of people, in order to identify, anticipate, and address potential social or economic problems, at national and regional levels.

This study presents a model to quantitatively estimate the spatial well-being (QoL) distribution across the EU-28 member states down to the municipal level, using tools offered by GIS. The model is weight-driven and based on Eurostat statistics on objective key QoL indicators, identified by the 2016 Eurostat Analytical report on subjective well-being and the 2013 EU-SILC ad-hoc module on well-being. Additionally, some Europe 2020 strategy targets of the European Commission, deemed to be important to a sense of personal well-being, are included, such as the risk of poverty or social exclusion and advanced educational attainment.

A climatic comfort component based on 1961-1990 climatic normals is added to estimate the importance of (a static) climate to QoL. Thermal comfort levels are obtained using the Universal Thermal Climate Index (UTCI) and Predicted Mean Vote (PMV), and overall climatic comfort levels are obtained as a weighted linear combination based on the classical Tourism Climatic Index (TCI).

To evaluate the performance of the model, individual mean country results for year 2014 are compared to actual country results of the 2013 EU and 2014 OECD subjective well-being surveys. The modeled spatial QoL distribution is also forecast into year 2020, using simple linear regression of the selected socioeconomic factors.

The findings suggest that the model is able to estimate actual well-being levels from quantitative country statistics. Even closer agreement should be possible with careful calibration of the model weights to the prevailing attitudes and priorities of each individual region/member country and using more sophisticated regression methods for forecasting. The findings also suggest that subjective well-being components could be isolated from the objective model baselines. Furthermore, a (static) climate seems to play a less important, and perhaps even negative, role than we might think, compared to most of the selected socioeconomic factors.

Keywords: Physical Geography and Ecosystem analysis, GIS, EU-28, EU-SILC, Europe 2020, Quality of Life, Well-being, UTCI, Tourism Climatic Index, Predicted Mean Vote, Analytic Hierarchy Process, Multi-Criteria Evaluation, Fuzzy membership

Advisor: **Dr. Micael Runnström**
Master degree project 30 credits in Geographical Information Sciences, 2017
Department of Physical Geography and Ecosystem Science, Lund University.
Thesis nr 71.

Table of Contents

Acknowledgements iv
Abstract v
Abbreviations viii
Tables ix
Figures x
1 INTRODUCTION 1
1.1 Quality of Life 1
1.2 Problem statement 2
1.3 Aim, objective, and research questions 2
1.4 Thesis outline 3
2 BACKGROUND 5
2.1 Well-being within the EU 5
2.2 Climatic comfort 6
2.2.1 The Tourism Climatic Index 6
2.2.2 The Universal Thermal Climate Index 7
2.3 Work flow 8
2.3.1 Calculation of UTCI and TCI 8
2.3.2 Selection and preparation of socioeconomic factors 9
2.3.3 Combination of factors 9
2.3.4 Evaluation of the MCE model 10
3 MATERIALS AND METHODS 11
3.1 Data 11
3.1.1 Study area 11
3.1.2 Climatic normals 12
3.1.2.1 Selection of climatic data 12
3.1.2.2 Climatic dataset limitations 12
3.1.3 Socioeconomic themes 13
3.1.3.1 Selected themes 13
3.1.3.2 Specific remarks regarding the data preparation 14
3.2 Methodology 15
3.2.1 Climatic comfort 15
3.2.1.1 UTCI data generation 15
3.2.1.2 UTCI value transformation 16
3.2.1.3 Other relevant TCI variables 18
3.2.1.3.1 Precipitation (R) 18
3.2.1.3.2 Wind speed (W) 19
3.2.1.3.3 Sunshine duration (S) 20
3.2.2 Constructing the TCI 21
3.2.2.1 Modification and calculation of the TCI 21
3.2.2.2 Conversion to a standard TCI scale 22
3.2.3 Preparation of socioeconomic factors 22
3.2.4 Combination of climatic and socioeconomic factors 22

3.2.4.1 Weighted sum using AHP method ... 22
3.2.4.2 Fuzzy overlay and Arithmetic mean ... 26
4 RESULTS ... 27
4.1 Climatic comfort ... 27
4.2 Combined socioeconomic and climatic QoL levels ... 29
5 DISCUSSION ... 33
5.1 Spatial distribution of climatic well-being/comfort ... 33
5.2 Spatial distribution of combined climatic and socioeconomic well-being ... 33
5.3 Comparison of the three combination methods ... 34
5.4 Comparison of weighted sum country results with survey results ... 35
5.5 The importance of climate to well-being ... 38
5.6 Sources of error and limitations of the study ... 38
6 CONCLUSIONS ... 41
References ... 43
Appendix A: NUTS 0 classification codes and country names ... 47
Appendix B: Fuzzy memberships of climatic TCI factors ... 48
Appendix C: Mean, annual total sunshine hours ... 52
Appendix D: Fuzzy memberships of socioeconomic factors ... 53
Appendix E: Socioeconomic theme metadata ... 57
Appendix F: Country statistics (NUTS 0) ... 59
Appendix G: Observation point NUTS level frequencies by country and theme ... 62
Appendix H: Exploratory Regression and OLS regression ... 66

Abbreviations

AHP	Analytic Hierarchy Process
CRU	Climatic Research Unit
EC	European Commission
EQLS	European Quality of Life Survey
ESS	European Social Survey
ET	Equivalent Temperature
EU-28	The 28 member states of the EU (2016)
EU-SILC	EU Statistics on Income and Living Conditions
GDP	Gross Domestic Product
GIS	Geographic Information Systems
MCE	Multi-Criteria Evaluation
NUTS	Nomenclature of Statistical Territorial Units
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PET	Physiologically Equivalent Temperature
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
PPS	Predicted Percentage Satisfied; Purchasing Power Standard
QoL	Quality of Life
TCI	Tourism Climatic Index
UTCI	Universal Thermal Climate Index

Tables

Table 1. Climatic input variables for UTCI and TCI calculation. 12
Table 2. Selected socioeconomic themes from Eurostat. 13
Table 3. PET to PMV mapping. 16
Table 4. Standard TCI numerical index value range. 22
Table 5. AHP pairwise comparison matrix. 24
Table 6. AHP comparison scale of relative importance. 25
Table 7. AHP weighting table. 25
Table 8. Projected % change 2014 to 2020 by country and socioeconomic theme. 31
Table 9. Comparison of three combination methods of mean country QoL levels. 34
Table 10. Country comparison of mean life satisfaction on an 11 point scale (0-10). 37
Table 11. Weight assignments in decreasing order of importance. 38
Table 12. Observed year 2014, forecast year 2020, Goodness-of fit (R^2), and standard error (SE) of the simple linear regression. 59
Table 13. Observation point NUTS level frequencies by country and theme. 62
Table 14. 12 factor model Exploratory Regression result. 66
Table 15. 12 factor model OLS regression analysis result. 67

Figures

Figure 1. General analysis flow. 8
Figure 2. EU-28 study area. 11
Figure 3. Relationship between PMV, PPD, PPS, and PET. 16
Figure 4. Fuzzy membership of the general triangular form. 17
Figure 5. PPS fuzzy membership function. 18
Figure 6. Precipitation fuzzy membership function. 19
Figure 7. Wind speed fuzzy membership function. 19
Figure 8. Sunshine fuzzy membership function. 21
Figure 9. Mean seasonal TCI. 27
Figure 10. Mean annual TCI. 28
Figure 11. 2014 and 2020 weighted sum QoL index, and change 2014 to 2020. 29
Figure 12. 2014 fuzzy AND & arithmetic mean QoL index. 32
Figure 13. Country comparison of mean life satisfaction. 35
Figure 14. Statistical correlation between 2014 MCE country means and the 2013 EU and 2014 OECD surveys. 36
Figure 15. EU-28 PPS mean, monthly fuzzy membership. 48
Figure 16. EU-28 Precipitation mean, monthly fuzzy membership. 49
Figure 17. EU-28 Sunshine hours mean, monthly fuzzy membership. 50
Figure 18. EU-28 Wind speed mean, monthly fuzzy membership. 51
Figure 19. EU-28 mean, annual total sunshine hours. 52
Figure 20. EU-28 fuzzy socioeconomic membership - part A. 53
Figure 21. EU-28 fuzzy socioeconomic membership - part B. 54
Figure 22. EU-28 fuzzy socioeconomic membership - part C. 55
Figure 23. EU-28 fuzzy socioeconomic membership - part D. 56
Figure 24. Variable distributions and scatter plots of the explanatory variables and the dependent variable. 68
Figure 25. Spatial distribution of the standardized OLS residuals. 69

1 INTRODUCTION

1.1 Quality of Life

The very first item of Article I-3 ("The Union's objectives") of the EU constitution (2004) emphatically states: "The Union's aim is to promote peace, its values and the well-being of its people." The constitution was never ratified, but the sentiment is clear: the well-being of the EU population is important. Arguably, well-being could be viewed as an important measure of the success of the social and economic policies and reforms implemented within the EU; indeed, measurements of well-being, or Quality of Life (QoL), are intended to help policy makers identify, anticipate, and address potential social or economic problems which might decrease these levels of well-being (Eurostat 2015).

Macroeconomic quantities such as gross domestic product (GDP) are no longer considered paramount indicators of well-being: Within the EU, well-being is currently measured multidimensionally through surveys, combining social, economic, and environmental indicators with subjective well-being (Huppert et al. 2009) within the Eurostat Quality of Life framework (2011). These surveys directly measure respondents' subjective (perceived) well-being and derive key indicators that drive well-being, such as health and material living conditions.

The 2016 EU-SILC analysis of key QoL factors (Eurostat 2016) explained variations in the responses to a 2013 EU-wide QoL survey (Eurostat 2013) and found that there exists a hierarchy of socioeconomic factors important to well-being, stretching from more basic, and objective, factors (such as income) to more subjective factors such as personal fulfillment or a sense of purpose/meaning.

Using the tools of Geographic Information Systems (GIS), this spatial study proposes a model to quantitatively estimate the current spatial QoL distribution across the EU-28 member states (Figure 2) down to the regional level, in terms of objective key QoL indicators identified by the EU-SILC analysis, within the Quality of Life framework. The model ignores the subjective well-being dimension, but may thus provide an objective baseline and an indication of the size of the contribution subjective well-being makes to overall well-being levels. In addition, the model enables future predictions and scenarios.

The model is weight-driven and uses readily available long-term Eurostat statistics on 11 QoL indicators selected by the author. Some overlap with Europe 2020 strategy targets (European Commission 2010), deemed also to be important to a sense of well-being, exists, such as the risk of poverty or social exclusion and advanced ("tertiary") educational attainment.

In order to observe how changes in the different QoL indicators might impact QoL levels, the spatial QoL distribution is also projected into the year 2020, based on simple linear regression of the socioeconomic factors.

Additionally, the model introduces a static climatic comfort component based on climatic normals to estimate the importance of climate to QoL. Climatic comfort is normally not considered in well-being surveys; however, research indicates that climate does play a role in well-being, although the extent remains uncertain.

In this study, "subjective well-being" refers to the perception people have of their well-being (long or short-term), whereas "objective well-being" refers to external factors, such as disposable income. QoL is here used interchangeably with well-being.

1.2 Problem statement

Both within the EU and within other regions/countries, there is a need to measure the well-being of people, in order to identify, anticipate, and address potential social or economic problems, at national and regional levels.

Well-being is multi-faceted:

a) Socioeconomic well-being.

   Well-being is linked directly to the social and economic policies and reforms of a country/region. This socioeconomic well-being is also intimately connected to our ability to adapt to the changing climate, in terms of the food supply, access to drinking water, adequate housing, etc.

b) Climatic well-being/comfort.

   The climate is not constant but is changing due to anthropogenic effects: This impacts not only the tourism industry, but our climatic well-being in a general sense such that regions may become too arid, too wet, too cold, or too hot. However, within the timescale of the socioeconomic well-being factors considered here, it makes sense to treat the climate as a constant.

c) Any other factors, such as the physical environment, infrastructure, and subjective short and long-term well-being in response to objective well-being factors, based on perceptions and expectations.

1.3 Aim, objective, and research questions

This study aims to:

a) Develop a quantitative model to assess the current well-being within the EU-28 member states, based on selected key objective socioeconomic factors and readily available climatic normal data.
b) Evaluate three different approaches to how the well-being factors may be combined.
c) Project the spatial distribution of the combined socioeconomic and climatic well-being of the EU-28 member states into the year 2020.

The objective is to identify and select key objective socioeconomic well-being factors, to combine them with climatic well-being, and map the spatial distribution, using Geographic Information Systems (GIS), within each of the EU-28 member states.

Five research questions are put forth:

1. What is the spatial pattern of seasonal climatic well-being/comfort within the EU-28?
2. What is the spatial pattern of combined mean, annual climatic and socioeconomic well-being within the EU-28?
3. Which of the three different approaches to how the well-being factors may be combined makes the most sense?

4. How do the model results compare to subjective well-being survey results, and is it warranted to project this model into the future?
5. How important is the (static) climate really within the EU-28 to a sense of well-being, in relation to the other, selected well-being factors?

1.4 Thesis outline

This thesis is organized as follows:

Section 1 presents an introductory background and a motivation for the study, with specific aims and research questions to be answered.

Section 2 presents a review of how well-being is defined and measured within the EU, including domains and objective and subjective drivers. Model-relevant, objective socioeconomic indicators and climatic comfort aspects are discussed, followed by an outline of the spatial analysis workflow.

Section 3 presents the study area, the sources, selection, and preprocessing of the spatial socioeconomic and climatic data, and the methods used for combining the well-being factors.

Section 4 presents the results of the spatial analysis, with mapped distributions of the climatic comfort and the combined climatic and socioeconomic QoL levels.

Section 5 discusses the results with regard to the research questions, evaluates the model, and lists possible sources of error and limitations of the study.

Section 6 presents the conclusions of the study, the cited references, and appendices containing the model-specific spatial factors, country-specific data regression statistics, and associated socioeconomic theme metadata.

This page intentionally left blank

2 BACKGROUND

2.1 Well-being within the EU

Well-being, or more precisely the perceptions people have of their quality of life, within the EU member states has become an increasingly important issue to policy makers. In recent years, the importance of factors beyond gross domestic product to QoL has been recognized, perhaps most influentially advocated by the Stiglitz-Sen-Fitoussi commission report on the Measurement of Economic Performance and Social Progress (2009).

Based on this report, the Eurostat Task Force on multidimensional measurement of quality of life (2011) was set up to inventory existing indicators, concepts, and methods for measuring QoL within the EU. It also made recommendations regarding good practices, the selection of QoL indicators, and the creation of synthetic QoL indicators (e.g. "material deprivation"). The Eurostat Task Force endorsed a multidimensional framework (the Eurostat Quality of Life framework) of 8+1 dimensions relevant to assess QoL:

- (i) Material living conditions;
- (ii) Health;
- (iii) Education;
- (iv) Productive and valued activities (incl. work);
- (v) Governance and basic rights;
- (vi) Leisure and social interaction;
- (vii) Natural and living environment;
- (viii) Economic and physical safety; and
- (ix) Overall experience of life.

Dimensions (i) to (viii) largely mirror the aims and objectives of Article I-3 of the EU constitution (2004). The last dimension, Overall experience of life, captures subjective measures of well-being developed in Round 3 of the European Social Survey (ESS), which Huppert et al. (2009) consider particularly relevant in economically developed nations due to the increasing impact subjective perception of well-being has on them (e.g. lowered subjective well-being despite high objective well-being). They also emphasize the central importance of measuring both functional (eudaimonic or long-term, sustainable) subjective well-being as well as short-term (hedonic) feelings of well-being.

During 2011-2012, the Third European Quality of Life Survey (EQLS) (Eurofound 2013) on subjective well-being among Europeans was conducted. In 2013, a new survey was conducted as an EU-SILC ad-hoc module on subjective well-being (Eurostat 2013), with analysis of the results presented in a 2015 "flagship" publication (Eurostat 2015).

The 2016 EU-SILC analysis (Eurostat 2016) is a study of this ad-hoc module and attempts to identify and rank key QoL indicators through multivariate regression analysis of the 2013 survey data. It categorizes well-being in terms of three domains: The first domain contains demographic factors such as age, gender, and nationality. The second domain adds socioeconomic factors such as personal health, disposable income, material deprivation, and social relationships. Finally, the third domain adds increasingly subjective factors difficult to quantify, such as mental health and trust.

The EU-SILC analysis concludes that on the whole, the strongest drivers of well-being are health, having a good job, material living conditions, and positive social relationships. Gender (women on average happier), age (middle-aged persons on average less happy), and country of residency are also shown to have different impacts on levels of life satisfaction.

No firm ranking, or relative importance, of these surveyed QoL indicators has been established by the EU-SILC analysis, as there is a dependency on both age, gender, and cultural background - only general indications (particularly the third domain).

Some well-being drivers are not possible to include in this model since EU source data for several key indicators are not available during a long enough time period (2013 only), and some have been intentionally omitted, such as:

a) <u>Leisure and social interaction (no data)</u>. This includes such things as having meaningful personal relationships with other people, and support (having someone to turn to when you need it).
b) <u>Governance and basic rights (no data)</u>. This includes corruption and trust in institutions, namely the police, the legal system, and the political system.
c) <u>Urbanization (omitted)</u>. This includes aspects such as overcrowding, commuting time, air pollution, and noise.
d) <u>The natural living environment (omitted)</u>. This includes aspects such as access to green areas, pollution, biodiversity, topography, coastal proximity, and recreation.
e) <u>Mental well-being (no data)</u>. This includes aspects such as stress, approach to family/working life, racial, cultural, and gender based discrimination, and depression.

2.2 Climatic comfort

2.2.1 The Tourism Climatic Index

Climate is no doubt also important in creating a sense of well-being. However, the extent to which climate plays a role still seems uncertain: Rehdanz and Maddison (2005), Brereton et al. (2008), and Maddison and Rehdanz (2011) indicate a larger impact, while Abdallah et al. (2008) indicate a smaller impact.

How to best measure climatic human comfort is also not a clear-cut issue, and many different methods have been proposed, but one classical approach still remains popular among researchers today: The Tourism Climatic Index (TCI) was developed (Mieczkowski 1985) specifically with tourism activities in mind and has been used extensively in modeling current and future tourism demand and desirability of tourism destinations. As such, it is a "passive" quantitative model of human climatic comfort, where only variables external to the human body are considered (no interaction). The TCI is defined as:

$$TCI = (4 * CId + CIa) + (2 * R + 2 * S + W) \qquad \textit{Eq. 1}$$

where the first term (4*CId + CIa) describes the physical thermal comfort aspect (50% weight) in terms of the sub-indices "daytime comfort" (CId) and "daily, average comfort" (CIa), and the second term (2*R + 2*S + W), where R is precipitation, S is the number of sunshine hours ("sunshine duration"), and W is the wind speed, describes the "aesthetic" comfort aspect (50% weight).

However, this classical definition has been criticized for being too much based on "expert knowledge" (too subjective) and for the values of the sub-indices CId and CIa being derived too arbitrarily from the relationship between temperature and relative humidity. Modified versions of this original TCI have been developed since to improve upon the physical thermal comfort aspect, using more advanced indices to more accurately model the effect of physical, climatic factors on humans (for a full listing of indices, see de Freitas and Grigorieva (2015)), and to suit more narrow applications such as beach tourism. A very early example of such a human thermal climate index is the passive index Effective Temperature (ET) (Houghten and Yaglou 1923). A later, popular example is the bioclimatic index Physiological Equivalent Temperature (PET) (Mayer and Höppe (1987); Höppe (1999)), which is an "active" model based on the human energy balance, i.e. how the human body responds and interacts thermally with the local environment, and which has been used extensively (e.g. by Kovács and Unger (2014) on a small selection of European cities).

2.2.2 The Universal Thermal Climate Index

A recent, alternate model of the physical thermal comfort aspect, the Universal Thermal Climate Index (UTCI), has been used here, as it has been shown to be highly objective and generally valid (Blazejczyk et al. (2012); Bröde et al. (2012); de Freitas and Grigorieva (2016)).

Like the PET index, the recently developed UTCI index is also an active index based on the human energy balance. To achieve a usability and general validity over that of other thermal indices, the UTCI has been developed "for any combination of air temperature, wind, radiation, and humidity," with UTCI defined as "the isothermal air temperature of the reference condition that would elicit the same dynamic response (strain) of the physical model" (Jendritzky et al. 2012, p. 421).

UTCI is derived from a multi-node model (Fiala et al. 2001) of the human heat balance, and is a function of the ambient air temperature, water vapor pressure, and wind speed (Błażejczyk et al. 2013), coupled with a clothing model (Havenith et al. 2012). The mean temperature variable is thus modified by the effects of vapor pressure, cloud cover, sun angle/latitude, and wind speed, to show the actual effect/human sensation of what is perceived. A higher UTCI value represents a higher thermal comfort level ("thermal comfort zone"), with the range +9.1 to +26 °C equivalent to no thermal stress (a value of 0 on a scale from -5 to +4 on a thermal stress scale) on the human body (Błażejczyk and Błażejczyk 2014).

UTCI has so far been used mainly in studies looking specifically at or comparing a limited number of physical locations (such as certain European cities) or smaller regions), but at least one recent study has employed it at a continental scale (Ge et al. 2016).

2.3 Work flow

The spatial analysis is divided into three major areas: (i) Spatial climate factors, (ii) Spatial socioeconomic factors, and (iii) Factor combination. The climatic data used to develop the climatic comfort (TCI) have a monthly temporal resolution (Table 1). The socioeconomic data have an annual temporal resolution (Table 2). The general work flow of the analysis is shown in Figure 1, with descriptions of the major method steps in the subsequent sections.

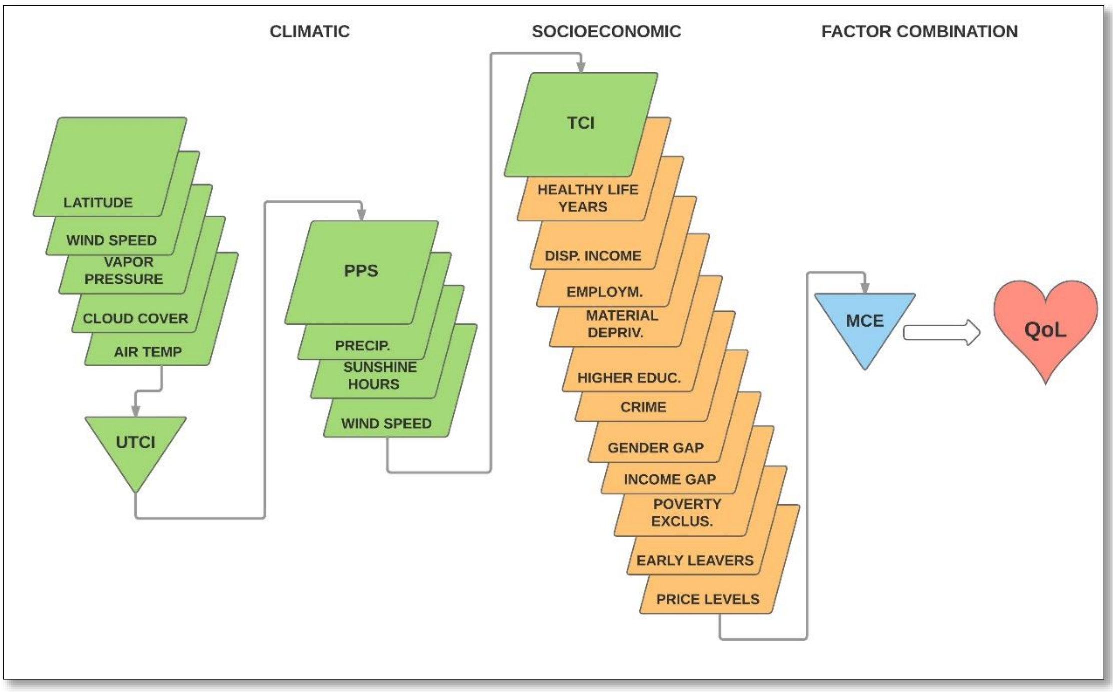

Figure 1. General analysis flow. The thermal climate index, UTCI, is calculated from climatic monthly normals and converted into PPS, a predicted thermal comfort distribution. The overall climatic comfort experience is then expressed as a scaled mean, annual TCI. Together with the 11 mean, annual socioeconomic factors, the TCI is combined in a Multi-Criteria Evaluation (MCE) into modeled QoL levels for the EU-28 (ref. to Table 1 and Table 2 for details on the spatial data layers).

2.3.1 Calculation of UTCI and TCI

As the calculation of UTCI is mathematically highly complex, a reasonable approach is to use a bioclimatological calculator capable of performing the task, such as the BioKlima 2.6 software package (freely available at http://www.igipz.pan.pl/Bioklima-zgik.html). The required BioKlima input variables are (ref. to Table 1):

1. Air temperature, monthly mean;
2. Wind speed, monthly mean;
3. Vapor pressure, monthly mean;
4. Cloud cover, monthly mean;
5. Latitude;
6. Time and day of calculation.

UTCI is here calculated at monthly value intervals (since the climatology is available only as monthly means). To keep the data processing overhead to a reasonable level, UTCI is calculated as a monthly average.

The resulting monthly UTCI values are transformed into the measure Predicted Percentage Satisfied (PPS) at a given UTCI value, using a mathematical relationship between UTCI and Predicted Mean Vote (PMV) of Fanger (1970), to obtain a thermal comfort distribution.

A mean monthly and mean annual TCI is finally calculated through a weighted combination of PPS, fuzzy precipitation, fuzzy sunshine duration, and fuzzy wind speed.

2.3.2 Selection and preparation of socioeconomic factors

Objective negative and positive socioeconomic factors for year 2014 are selected by the author, based on the Eurostat Task Force 8+1 multidimensional framework, on aspects of well-being in the 2013 Third European Quality of Life Survey (Eurofound 2013), and on the key QoL indicators determined by the 2016 EU-SILC analysis (Eurostat 2016). Macro-level, indirect QoL factors of the Europe 2020 strategy (European Commission 2010) are also considered.

The chosen factors are also forecast into the target year 2020 using simple linear regression, i.e. the fitting of a linear trend function to the observed data points, with associated goodness-of fit (R^2) as a measure of the fit (where "0" equals no fit/linearity and "1" equals perfect fit/linearity) (ref. to Eq. 8 and Appendix F: Country statistics (NUTS 0)).

2.3.3 Combination of factors

Three different ways of how the factors could reasonably be combined in a Multi-Criteria Evaluation (MCE) are explored:

a. Weighted sum

MCE in the form of a linear combination of factors, a weighted sum, is performed. The weights are based on conclusions drawn by the author (Section 3.2.4.1) from the 2016 EU-SILC analysis and constructed using the pairwise factor comparison method of the Analytic Hierarchy Process (AHP) introduced by Thomas Saaty (Saaty 1980), in an attempt to reflect the preferences of a majority of the European peoples.

b. Fuzzy intersection

A fuzzy overlay of the mean, annual factors in the form of an intersection (AND), overlaps between the various data layers, is performed. Intersection simply means that the minimum value of each individual cell for all the input factors is found, and it is therefore minimizing in its scope.

c. Arithmetic mean

The arithmetic mean of the mean, annual factors for each individual cell is found. The arithmetic mean differs from the weighted sum method in that no weighting is performed on the input factors – they are all treated as equally important.

2.3.4 Evaluation of the MCE model

The spatial analysis result for year 2014 (the baseline of objective measurements) is compared to the 2013 EU-SILC (Eurostat 2015) and 2014 OECD survey results (OECD 2016) of self-reported (subjective) well-being.

3 MATERIALS AND METHODS

3.1 Data

3.1.1 Study area

Data for the study area of the EU-28 member states (Figure 2) was obtained from Eurostat (European Commission 2016) as a Europe-wide (NUTS 0-3) polygon data layer ("NUTS_RG_01M_2013").

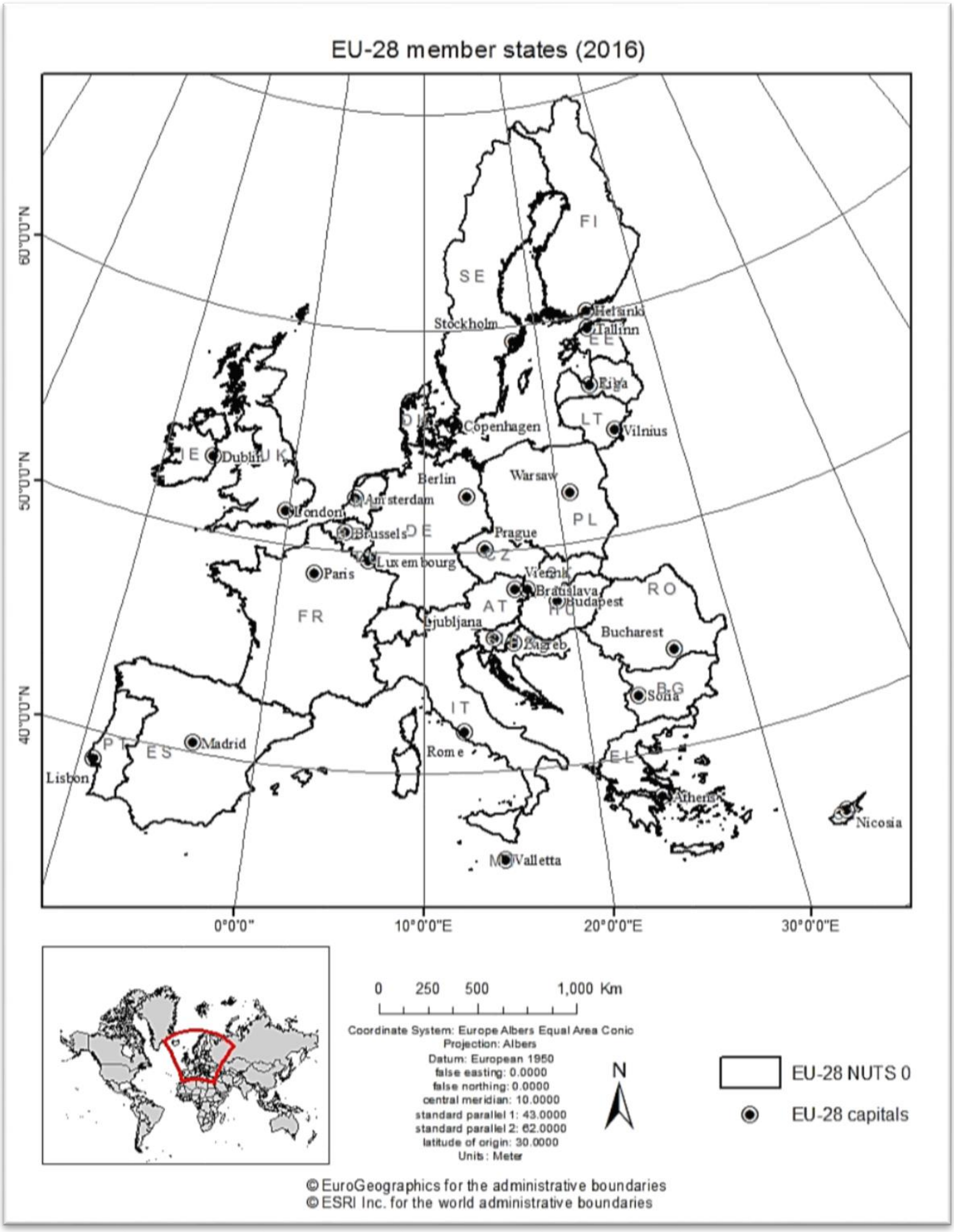

Figure 2. EU-28 study area.

Nomenclature of territorial units for statistics (NUTS) is a classification of the territory of the EU, where: NUTS 0 corresponds to countries; NUTS 1 major socioeconomic regions; NUTS 2 basic regions for regional policy application; and NUTS 3 small regions/municipalities (ref. to Appendix A for NUTS 0 member country codes). The NUTS classification used here is the latest available (2013).

The polygon data layer was modified to include only the EU-28 member states and was split into the constituent NUTS levels. In order to shrink the spatial extent, some outlying regions were omitted, e.g. the Canary Islands, Madeira, and French Guyana, and the data layers were projected into the Europe Albers Equal Area Conic projection. The unique NUTS_ID field was used throughout as a common join field.

3.1.2 Climatic normals

3.1.2.1 Selection of climatic data

The BioKlima UTCI calculation requires certain specific climatic input variables (Table 1). It was deemed important to try to capture differences in climatic comfort down to the municipal level. The most current and well documented datasets found at this high resolution, containing all the required input variables as climatic normals, were the gridded mean, monthly climatic CL 2.0/2.1 datasets from the Climatic Research Unit (CRU) at the University of East Anglia, for the period 1961-1990 (New et al. (2002); T. et al. (2004)). The climatic normals were interpolated from station data as a function of latitude, longitude, and elevation using thin-plate spline surfaces (3D); elevation is thereby used as a co-predictor.

Table 1. Climatic input variables for UTCI and TCI calculation. The required BioKlima input variable names are shown in parentheses. The sunshine fraction is used only in the calculation of the sunshine duration for the TCI, as is the precipitation. The 10 arcminute spatial resolution used in this study corresponds to a cell size of ~17 km x 17 km.

Input variable	Dataset	Unit of meas.	Temporal resolution	Spatial resolution	Time span	Spatial extent
Mean surface air temperature (t)	CRU CL 2.0	°C	month	10 arcmin.	1961-1990	global
Wind speed, 10 m height (v10m)	CRU CL 2.0	m/s	month	10 arcmin.	1961-1990	global
Vapor pressure (e)	CRU CL 2.1	hPa	month	10 arcmin.	1961-1990	EU-28 exc Cyprus
Cloud cover (N)	CRU CL 2.1	%	month	10 arcmin.	1961-1990	EU-28 exc Cyprus
Precipitation	CRU CL 2.0	mm	month	10 arcmin.	1961-1990	global
Sunshine fraction	CRU CL 2.0	%	month	10 arcmin.	1961-1990	global

3.1.2.2 Climatic dataset limitations

Cyprus was not within the spatial extent of the vapor pressure or cloud cover data layers. Therefore, Cyprus had to be omitted from the final analysis of the EU-28 member states.

3.1.3 Socioeconomic themes

3.1.3.1 Selected themes

In the current analysis gender and/or age differentiated data were not considered; unless otherwise specified, the data used in this study included both men and women, as well as all ages (both children and adults). With the Europe 2020 strategy in mind, the selected socioeconomic data were forecast into the target year 2020, using simple linear regression, based on the available annual records (mainly 2004-2015) (Appendix F: Country statistics (NUTS 0)).

The most current and complete Eurostat datasets available were for year 2014, as the year 2015 datasets were generally either incomplete or nonexistent. In addition, gender earnings gap data were available only in four-year increments, where 2014 was the last available year. For these reasons, the year chosen to represent the most current and complete record was 2014. 15,473 observation points were used.

The relevant Eurostat data (Table 2) were in most cases available down to the regional NUTS 2, or even NUTS 3, level, but some data varied by country (NUTS 0) also within each theme (Appendix G: Observation point NUTS level frequencies by country and theme, and Appendix E: Socioeconomic theme metadata).

Table 2. Selected socioeconomic themes from Eurostat. Depending on data availability, in some cases multiple tables had to be consulted to obtain a more complete range of country/regional data. The Eurostat data tables may be subject to change over time due to continuous revision and/or updates.

Theme	**Relevance to QoL**	**Temporal res.**	**Spatial res.**	**Time span**	**Eurostat data table**	**Unit of measure / scale**
Healthy Life Years at birth as a percentage of life expectancy	EU-SILC main measure	year	NUTS 0	2004-2015	hlth_hlye	%
Real adjusted gross disposable income of households per capita	EU-SILC core measure of material living conditions	year	NUTS 0	2004-2015	tec00113	PPS
Employment (total), ages 20-64	Social protection/ macro-level, indirect impact	year	NUTS 0/2	2004-2015	tgs00102/ tsdec410	% of pop.
Severe material deprivation	Social protection	year	NUTS 0/2	2004-2015	tgs00104/ tespm030	% of pop.
Tertiary educ. attainment (total), ages 30-34	Social protection/ sustainable devel.	year	NUTS 2	2004-2015	edat_lfse_12	% of pop.

Theme	Relevance to QoL	Temporal res.	Spatial res.	Time span	Eurostat data table	Unit of measure / scale
Crimes recorded (aggregate)	Physical security	year	NUTS 0-3	2008-2010	crim_gen_reg	number
Gender equality (overall earnings gap)	Equality/ sustainable devel.	year	NUTS 0	2002-2014 (every 4 yrs)	teqges01	% gap
Gini coefficient of equivalised disposable income	Equality/ social protection/ security/ macro-level, indirect impact	year	NUTS 0	2004-2015	tessi190	0-100
People at risk of poverty or social exclusion	Social protection/ macro-level, indirect impact	year	NUTS 0/2	2004-2015	tgs00107/ tsdsc100	% of pop.
Early leavers from education/ training (total), ages 18-24	Sustainable devel./ macro-level, indirect impact	year	NUTS 2	2011-2015	edat_lfse_16	% of pop.
Comparative price levels of final consumption by private households including indirect taxes	Cost of living	year	NUTS 0	2004-2015	tec00120	EU-28 = 100

3.1.3.2 Specific remarks regarding the data preparation

a) HEALTHY LIFE YEARS: The Eurostat source data were available only as male/female data. Averages of the male/female data were calculated and used.
b) DISPOSABLE INCOME: No data were available for Luxembourg or Malta. In order to make possible a comprehensive final analysis of all member countries, the EU-28 average values were substituted for these countries.
c) SEVERE MATERIAL DEPRIVATION: Due to lack of data for 2014 in the following NUTS regions, data were created artificially using simple linear regression: Belgium (BE1, BE2, BE3). In addition, data for some NUTS regions exhibited a steadily declining trend, which projected into 2014 and/or 2020 resulted in a negative number. As this clearly would be meaningless, a value of 0 (zero) was substituted instead.
d) 30-34 TERTIARY EDUCATION ATTAINMENT: The observed data for the Finnish region of Åland (NUTS ID FI20) exhibited a steadily declining trend,

which projected into 2020 resulted in a negative number. As this clearly would be meaningless, a value of 0 (zero) was substituted instead.

e) CRIMES RECORDED (AGGREGATE): For ease of comparison, the number of recorded crimes per NUTS area were converted into number of crimes/km^2 ("crime density"). Only 3 years of NUTS 3 crime data were available (2008-2010), which naturally limited the usefulness of future projections. However, due to the impact of local crime on the sense of security/peace of mind of people (Eurofound 2013), it was decided to include it. Data for 2014 were created artificially using simple linear regression. In addition, data for some NUTS regions exhibited a steadily declining trend, which projected into 2014 and/or 2020 resulted in a negative number. As this clearly would be meaningless, a value of 0 (zero) was substituted instead.

f) GENDER EARNINGS GAP: Very few data points were available for Greece, France, and Croatia; however, an attempt was made to create both year 2014 and year 2020 data for Greece using simple linear regression. For Croatia, only a single data point existed (2010), which was also used for both year 2014 and year 2020. For France, only a single data point existed (2014), which was also used for year 2020.

g) 18-24 EARLY LEAVERS: Data for some NUTS 2 regions exhibited a steadily declining trend, which projected into 2020 resulted in a negative number. As this clearly would be meaningless, a value of 0 (zero) was substituted instead. The following NUTS regions were affected: Austria (AT33), Germany (DE23), Spain (ES13), Greece (EL30, EL42, EL53, EL54, EL61, EL62, EL63), France (FR23, FR61, FR62, FR72), Hungary (HR03), Italy (ITH3), Portugal (PT17), United Kingdom (UKD6, UKE1, UKI3, UKI4, UKK3, UKM6).

3.2 Methodology

3.2.1 Climatic comfort

3.2.1.1 UTCI data generation

Work flow for generation of a UTCI raster:

a) Create the study area of the EU-28 member states using Europe Albers Equal Area Conic projection.
b) Create a raster extraction mask from the climatic input grids, clipped to the study area, with 10 arcminute/~17 km x 17 km cells.
c) Convert the clipped mask grid into a point data layer (15,473 discrete cell center points) and adding LAT/LON geometry.
d) Extract the climatic input grids by mask to the study area, and convert them to point data layers.
e) Export the attribute tables as ASCII text files (common POINTID field), combining them into single, monthly BioKlima input files.
f) Using the BioKlima software, calculate the required sun altitude (hSi, a BioKlima required input) and UTCI for all LAT points, and for each month of the year.
g) Join the monthly UTCI output tables to the EU-28 study area points.
h) Rasterize the point data layers.

3.2.1.2 UTCI value transformation

The UTCI raster values need to be transformed into a suitable thermal comfort scale, corresponding to how people actually perceive their physical climatic environment as it changes (neutral, too cold, too warm, etc.) in terms of the percentage of people satisfied or dissatisfied. Such a climatic comfort scale was established by Fanger (1970), called PMV. It analytically calculates the Predicted Percentage Dissatisfied (PPD) persons expected at a given local equivalent temperature, as an inverse Gaussian distribution, and with a corresponding PPS as the Gaussian distribution.

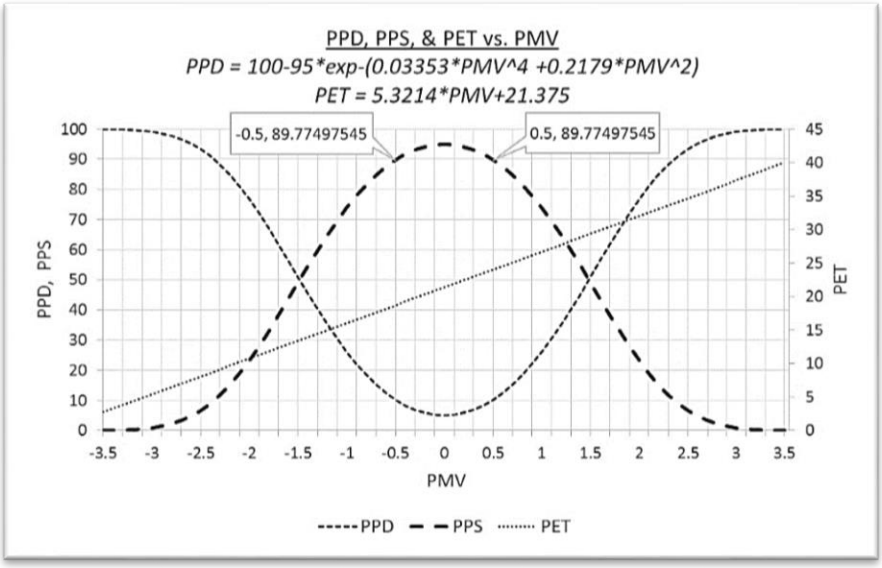

Figure 3. Relationship between PMV, PPD, PPS, and PET. PET is measured in °C, while PPD and PPS are measured in %.

The commonly used climatic comfort index PET is similar to UTCI (both also conveniently use °C as the unit of measure) in that it utilizes physical environment factors and the human physiological response (the human energy balance) to calculate an equivalent temperature. It has been shown (Matzarakis et al. 1999) that PET may be mapped linearly onto PMV for a direct correspondence:

Table 3. PET to PMV mapping. This relationship (Eq. 3) corresponds to the straight line shown in Figure 3.

PMV	-3.5	-2.5	-1.5	-0.5	0.5	1.5	2.5	3.5
PET	4	8	13	18	23	29	35	41

Most notable is that PMV predicts that no more than 95% of the votes (the thermal perception of respondents), and no less than 5%, may be in agreement – i.e. there will always be at least 5% satisfied or dissatisfied respondents, regardless of temperature. Among satisfied respondents, the 90% PPS range corresponds to an equivalent (PET) temperature range of +18 to +23 °C, where most people feel thermally neutral (equivalent to a PMV range of -0.5 and 0.5) (Matzarakis et al. 1999). This local temperature/PMV range has been proposed as a suitable thermal comfort range for Western/Central European people (Lin and Matzarakis 2008).

Comparisons (Blazejczyk et al. (2012); de Freitas and Grigorieva (2016)) of commonly used thermal comfort indices indicate a strong agreement between the predictions of PET and UTCI (Blazejczyk et al. (2012) report an overall R^2 value of 0.9642), and that PET and UTCI both arrive at very similar equivalent temperature values, albeit through different methods, and particularly within the PET range [0, 45] of interest here (Figure 3). It could then be reasonably concluded that, setting UTCI equal to PET, UTCI values may be transformed into PPS values by substitution using Eq. 2 (ASHRAE 2004, p. 5), Eq. 3, and Eq. 4:

$$PPD = 100 - 95 * e^{-(0.03353*PMV^4+0.2179*PMV^2)} \qquad \textit{Eq. 2}$$

$$PMV = \frac{PET - 21.375}{5.3214} \qquad \textit{Eq. 3}$$

$$PPS = 100 - PPD \qquad \textit{Eq. 4}$$

In order to minimize possible classification errors and to enable a fuzzy overlay analysis, the transformed UTCI values (PPS values) were linearly converted into fuzzy membership values, $\mu_{PPS}(x)$, in the range [0, 1], using a conditional fuzzy membership function (Eq. 5) of the general triangular form (adapted from Schubert (2004)):

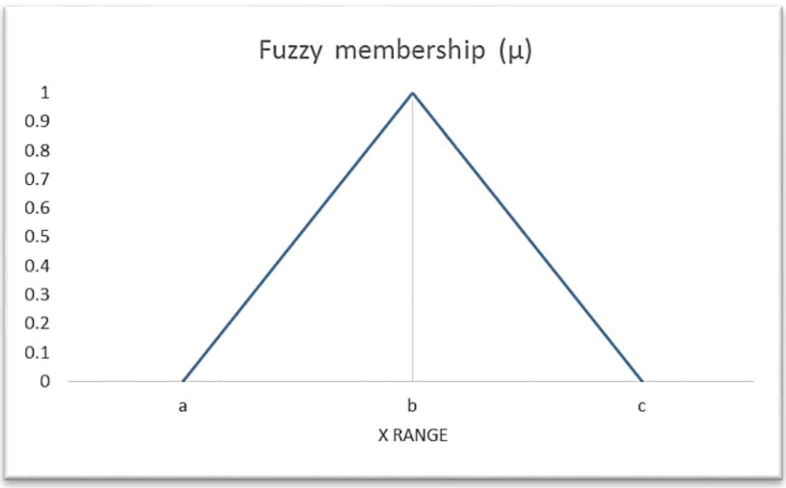

Figure 4. Fuzzy membership of the general triangular form.

$$\mu(x) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a < x \leq b \\ \frac{c-x}{c-b} & b < x < c \\ 0 & x \geq c \end{cases} \quad \textit{Eq. 5}$$

The constants a and b (left half of the function) here correspond to the possible minimum and maximum PPS values, respectively, of the original PPS value range [0, 95].

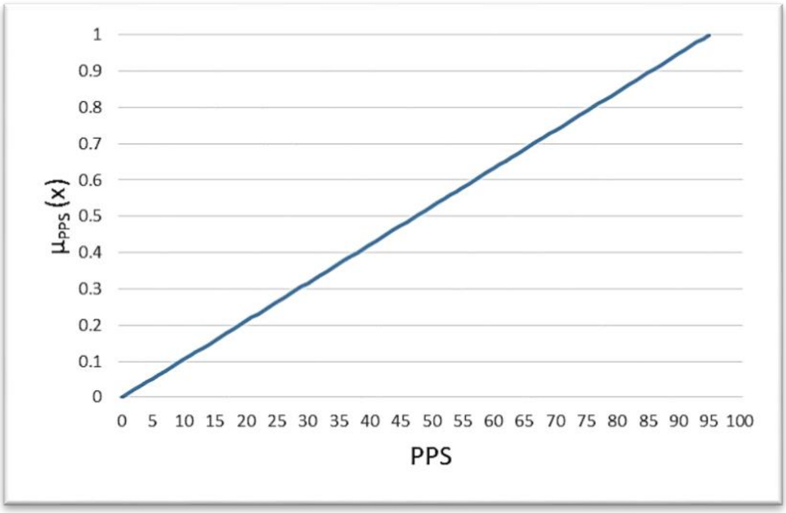

Figure 5. PPS fuzzy membership function. The entire PPS value range has been selected.

3.2.1.3 Other relevant TCI variables

3.2.1.3.1 Precipitation (R)

There exists a range where the amount of precipitation could be considered ideal, .i.e. where the climate is neither too dry, nor too wet for human comfort. In this study, essentially the original classification of Mieczkowski (1985) was used, where mean monthly precipitation ≥150 mm was considered too high for comfort. However, Mieczkowski rates precipitation ≤15 mm the highest, which for tourism purposes probably would be ideal, but would likely prove problematic in case of permanent residency. For the purposes of this study, this lowest range was therefore considered unacceptable.

Using Eq. 5, the mean monthly and mean annual precipitation values were converted into fuzzy membership values, $\mu_{\text{prec}}(x)$, in the range [0, 1], with b = 15 and c = 150 such that $\mu_{\text{prec}}(x) = 0$ for x ≤ b and x ≥ c (Appendix B: Fuzzy memberships of climatic TCI factors).

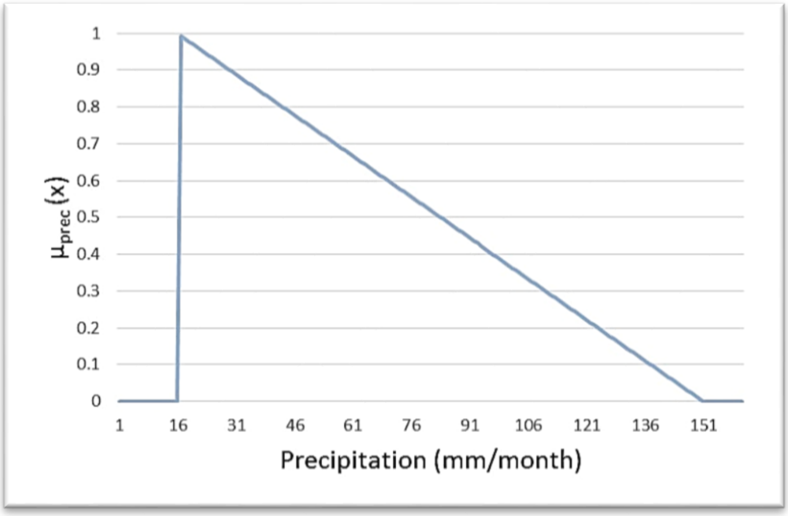

Figure 6. Precipitation fuzzy membership function. The lower and upper ends of the precipitation value range have been deselected.

3.2.1.3.2 Wind speed (W)

The findings of Brereton et al. (2008) indicate that wind speed clearly affects QoL levels negatively. For the purposes of this study, less wind is therefore considered better (more comfortable).

Using Eq. 5, the mean monthly and annual wind speed values in m/s (observed range [0.59, 8.71]), were converted into fuzzy membership values, $\mu_{wind}(x)$, in the range [0, 1], with b = 0.59 and c = 8.71 (Appendix B: Fuzzy memberships of climatic TCI factors).

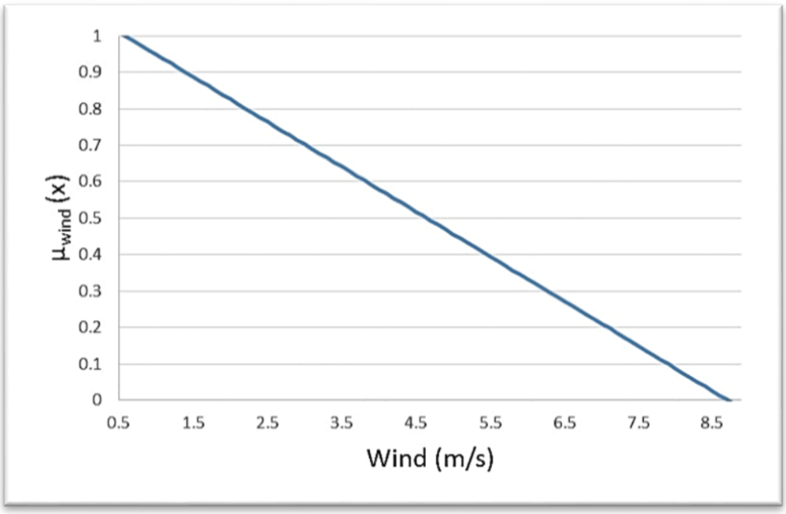

Figure 7. Wind speed fuzzy membership function. The entire wind speed value range has been selected.

3.2.1.3.3 Sunshine duration (S)

Sunshine duration (hrs. of sun/month) was obtained by multiplying the following two values:

1. Day length ((total) number of daylight hours (in each month)).

This dataset was generated by calculating the day length (D, in hours) for a set of latitude sampling points (L, 15,473 study area cell centers) and for each day of the year (J), applying the following equation (Forsythe et al. 1995, p. 89):

$$D = 24 - \left(\frac{24}{\pi}\right) * acos\left(\frac{sin\left(0.8333 * \frac{\pi}{180}\right) + sin\left(\mathrm{L} * \frac{\pi}{180}\right) * sin(P)}{cos\left(\mathrm{L} * \frac{\pi}{180}\right) * cos(P)}\right) \qquad Eq.\ 6$$

where

$$P = asin\left(0.39795 * cos\left(0.2163108 + 2 * atan\left(0.9671396 * tan\left(0.00860 * (J - 186)\right)\right)\right)\right)$$

and
L = latitude in decimal degrees
J = day of the year (1-365)

By summing the calculated daily day length values D for each individual month, monthly total day length values (total hours of daylight in each month) were obtained.

2. Sunshine fraction (mean, monthly % sunshine of possible day length).

The sunshine fraction essentially denotes the percent of time that the sun irradiates the ground, the insolation, while above the horizon (the day length), as a mean, monthly value.

In addition, the mean annual total sunshine values, i.e. simply the summed monthly totals, were also calculated and mapped (Figure 19) for general reference.

For this study, more hours of sunshine is considered better (more comfortable). Using Eq. 5, the mean monthly total sunshine hour min/max values (range [0, 434.98]) were converted into fuzzy membership values, $\mu_{\mathrm{sun\_mon}}(x)$, in the range [0, 1], with a = 0 and b = 434.98 (Figure 8 and Appendix B: Fuzzy memberships of climatic TCI factors).

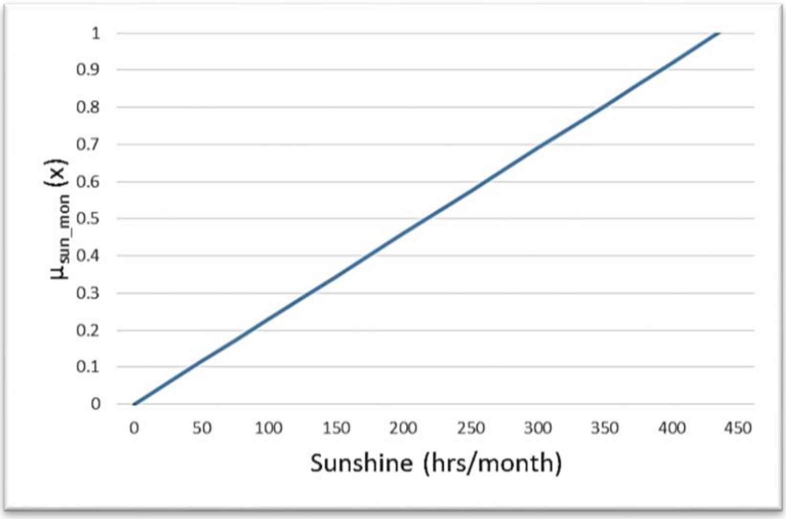

Figure 8. Sunshine fuzzy membership function. The entire sunshine value range has been selected.

Similarly, the mean annual total sunshine values were also converted into fuzzy membership values, using the mean annual range of hour totals.

3.2.2 Constructing the TCI

3.2.2.1 Modification and calculation of the TCI

A modified TCI was generated using the classical weighting scheme of Mieczkowski (1985) (Eq. 1), but with no accommodation for negative value ranges:

- mean monthly/annual PPS (physical thermal comfort component; 50%)
- mean monthly/annual precipitation (aesthetic component; 20%)
- mean monthly/annual sunshine duration (aesthetic component; 20%)
- mean monthly/annual wind speed (aesthetic component; 10%)

The fuzzy membership values of Section 3.2.1 were combined as a weighted sum, separately for each month and separately for the year, with w_j denoting the assigned weight of the jth fuzzy membership class:

$$TCI(x) = \sum_{j=1}^{k} w_j \, \mu_j(x) \qquad where \sum_{j=1}^{k} w_j = 1, \qquad for\; w_j > 0 \qquad \text{Eq. 7}$$

In order to combine the resulting mean annual TCI using MCE with the various socioeconomic factors, the mean annual TCI also needed to be normalized to the range [0, 1] using Eq. 5, such that the maximum TCI value was set to 1 and the minimum value was set to 0.

3.2.2.2 Conversion to a standard TCI scale

For ease of comparison with other TCI analyses, the resulting TCI values were also rescaled (Figure 9 and Figure 10) to a modified, standard TCI scale [0, 100] by simply multiplying the fuzzy membership values by 100 (Table 4).

Table 4. Standard TCI numerical index value range. Unlike the original TCI scale, no negative value ranges are included here.

Numerical index value	Descriptive category
90-100	Ideal
80-90	Excellent
70-80	Very good
60-70	Good
50-60	Acceptable
40-50	Marginal
30-40	Unfavorable
20-30	Very unfavorable
10-20	Extremely unfavorable
0-10	Impossible

3.2.3 Preparation of socioeconomic factors

Socioeconomic factor work flow:

a) The raw Eurostat data were prepared and target year 2020 data were created, if data from at least two earlier years were available, using simple linear regression (Eq. 8). If the dependent variable y = f(x), then the linear regression line is described by:

$$f(x) = a + bx, \qquad where \quad a = \overline{y} - b\overline{x} \qquad\qquad Eq.\ 8$$

$$and \qquad b = \frac{\sum(x - \overline{x})(y - \overline{y})}{\sum(x - \overline{x})^2}$$

where $\overline{x}$ and $\overline{y}$ are the sample means of known *x* and *y*.

b) The prepared data were joined to the appropriate EU-28 NUTS level polygons using "NUTS_ID" as a common key and combined into a single polygon data layer for each class. Where available, NUTS 3 was given priority over NUTS 2, NUTS 2 over NUTS 1, etc. The polygon data layers were rasterized and a linear fuzzy membership, in the range [0, 1], was calculated for each factor (inverted where necessary) using either the left or the right half of Eq. 5, in order to combine them with the climatic comfort factor.

3.2.4 Combination of climatic and socioeconomic factors

3.2.4.1 Weighted sum using AHP method

The climatic comfort factor was related to the selected socioeconomic factors for year 2014 and year 2020 respectively, using a weighted sum with weights determined using AHP (a full description of AHP follows below), to determine the individual weights before they were combined as a weighted sum using Eq. 7.

The assignment of factor weights is critical. Decancq and Lugo (2012) in their overview of different weight assignment approaches discuss the difficulty of assigning weights to QoL index factors: They argue that the weight assignment is either a factual, data driven judgment ("is"-driven statements), a value judgment (normative or "ought to be"-driven statements), or a hybrid of the two. The hybrid approach attempts to avoid the shortcomings of both, by valuating observed data. The weighting approach chosen here is in a sense a hybrid as it is based on surveyed opinions, but utilizes the commonly used, normative AHP method, i.e. a subjective valuation (expert opinion) of statistically derived correlations between QoL survey results and relevant indicators.

Some factors, e.g. health, employment, and material deprivation, are clearly highly important, whereas other factors, e.g. gender gap or educational attainment level, are more diffuse and subjective (Eurostat 2016). The following subjective determinations were made by the author:

1. Health: Health was determined to generally be the single most important factor.
2. Disposable income: This is the classic measure of QoL and is the core EU-SILC measure of material living conditions.
3. Employment: Employment, aside from the purely practical aspect, also has been shown to provide a sense of self-worth and purpose. As such it was rated very highly.
4. Material deprivation: Second to employment, material deprivation has also been shown to be very important to QoL, in terms of having basic needs met (e.g. Maslow's classical hierarchy of needs). This indicator includes the state of housing, such as the ability to keep the dwelling sufficiently warm.
5. Education: Attainment of a higher education level has been linked to a higher level of life satisfaction.
6. Crime: Aside from the purely practical aspect, the impact of local crime on the sense of security/peace of mind of people is significant (Eurofound 2013), offsetting many other QoL factors.
7. Gender gap: The existing gender earnings gap is a fundamental and essential societal problem; however, it is difficult to quantify its importance in relation to other factors, but Eurostat (2015) found it to have a larger, negative effect on financial satisfaction among women than among men.
8. Income gap: Among the macro-level indicators, Eurostat (2016) found the income gap (GINI) to have one of the highest (negative) correlations with life satisfaction.
9. Risk of poverty or social exclusion: This is a "headline target" of the Europe 2020 strategy (European Commission 2010). A higher risk of poverty or social exclusion may be viewed as a direct reflection of what the modern welfare state can afford its citizens, in terms of providing a social net; knowing help is available should you need it is a great comfort to the individual. Additionally, poverty and/or social exclusion may lead to marginalization and potentially unrest and violence, as evidenced by the recent terror events in France.
10. Early leavers: Another headline target of the Europe 2020 strategy, relevant to sustainable development.

11. Price levels: The cost of living is important to most people and should be included here.
12. Climate: Following the discussion in Section 2.2.1, climatic comfort is a relevant factor and is also one of the variables examined here.

The AHP method is a two-step process:
Each factor in the left-most column of Table 5 is compared in terms of relative importance in a pairwise fashion to every other factor in the top row, and an index value (Table 6) is assigned such that each factor receives a column total. Each factor value is then divided by its column total (which normalizes it) and the result is entered into the corresponding cell in the weights table (Table 7). In this table, the row total of each factor is divided by the number of factors (12), finally arriving at the weighting for each factor in the right-most column (the column totals in this table are merely a verification of the normalization). Note that the weights always sum to 1.

Table 5. AHP pairwise comparison matrix. Note that the diagonal values always equal 1, and that the lower half of the matrix simply is the inverse of the upper half.

FACTOR	Health	Disp. income	Empl.	Mat. depriv	Educ.	Crime	Gender gap	Income gap	Poverty risk	Early leavers	Price levels	Climate
Health	**1**	3	3	2	7	6	8	4	4	8	8	7
Disp. income	0.330	**1**	0.333	0.200	5	4	5	4	0.250	8	3	5
Empl.	0.333	3	**1**	3	6	4	8	4	5	8	5	5
Mat. depriv.	0.500	5	0.330	**1**	9	6	9	5	5	8	7	8
Educ.	0.143	0.200	0.170	0.110	**1**	0.167	4	2	0.143	5	4	5
Crime	0.167	0.250	0.250	0.170	6	**1**	9	6	4	8	8	7
Gender gap	0.125	0.200	0.130	0.110	0.250	0.110	**1**	0.200	0.167	0.167	0.200	0.250
Income gap	0.250	0.250	0.250	0.200	0.500	0.170	5	**1**	0.250	4	0.167	0.500
Poverty risk	0.250	4	0.200	0.200	7	0.250	6	4	**1**	7	5	5
Early leavers	0.125	0.125	0.130	0.130	0.200	0.130	6	0.250	0.140	**1**	0.167	0.143
Price levels	0.125	0.333	0.200	0.143	0.250	0.130	5	6	0.200	6	**1**	1
Climate	0.143	0.200	0.200	0.125	0.200	0.140	4	2	0.200	7	1	**1**
TOTAL	**3.49**	**17.56**	**6.18**	**7.38**	**42.40**	**22.09**	**70.00**	**38.45**	**20.36**	**70.17**	**42.53**	**44.89**

Table 6. AHP comparison scale of relative importance.

Equally	1	Equally	1/1
Equally or slightly more	2	Equally or slightly less	1/2
Slightly more	3	Slightly less	1/3
Slightly to much more	4	Slightly to much less	1/4
Much more	5	Much less	1/5
Much to far more	6	Much to far less	1/6
Far more	7	Far less	1/7
Far more to extremely more	8	Far less to extremely less	1/8
Extremely more	9	Extremely less	1/9

Table 7. AHP weighting table. Note that the individual weights, here rounded up to two decimals, always sum to 1.

FACTOR	Health	Disp. income	Empl.	Mat. depriv.	Educ.	Crime	Gender gap	Income gap	Poverty risk	Early leavers	Price levels	Climate	**WEIGHT**
Health	0.286	0.171	0.485	0.271	0.165	0.272	0.114	0.104	0.197	0.114	0.188	0.156	**0.21**
Disp. income	0.095	0.057	0.054	0.027	0.118	0.181	0.071	0.104	0.012	0.114	0.071	0.111	**0.09**
Empl.	0.095	0.171	0.162	0.406	0.142	0.181	0.114	0.104	0.246	0.114	0.118	0.111	**0.16**
Mat. depriv.	0.143	0.285	0.054	0.135	0.212	0.272	0.129	0.130	0.246	0.114	0.165	0.178	**0.17**
Educ.	0.041	0.011	0.027	0.015	0.024	0.008	0.057	0.052	0.007	0.071	0.094	0.111	**0.04**
Crime	0.048	0.014	0.040	0.023	0.142	0.045	0.129	0.156	0.197	0.114	0.188	0.156	**0.10**
Gender gap	0.036	0.011	0.020	0.015	0.006	0.005	0.014	0.005	0.008	0.002	0.005	0.006	**0.01**
Income gap	0.072	0.014	0.040	0.027	0.012	0.008	0.071	0.026	0.012	0.057	0.004	0.011	**0.03**
Poverty risk	0.072	0.228	0.032	0.027	0.165	0.011	0.086	0.104	0.049	0.100	0.118	0.111	**0.09**
Early leavers	0.036	0.007	0.020	0.017	0.005	0.006	0.086	0.007	0.007	0.014	0.004	0.003	**0.02**
Price levels	0.036	0.019	0.032	0.019	0.006	0.006	0.071	0.156	0.010	0.086	0.024	0.022	**0.04**
Climate	0.041	0.011	0.032	0.017	0.005	0.006	0.057	0.052	0.010	0.100	0.024	0.022	**0.03**
TOTAL	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

3.2.4.2 Fuzzy overlay and Arithmetic mean

A fuzzy overlay of the mean, annual factors was performed where the intersection (minimum value) between the various data layers was found. The arithmetic mean of the mean, annual factors for each individual cell was also calculated.

4 RESULTS

4.1 Climatic comfort

The results of the climatic comfort model component (rescaled Tourism Climatic Index (TCI)) are shown in Figure 9 at a quarter-annual timescale.

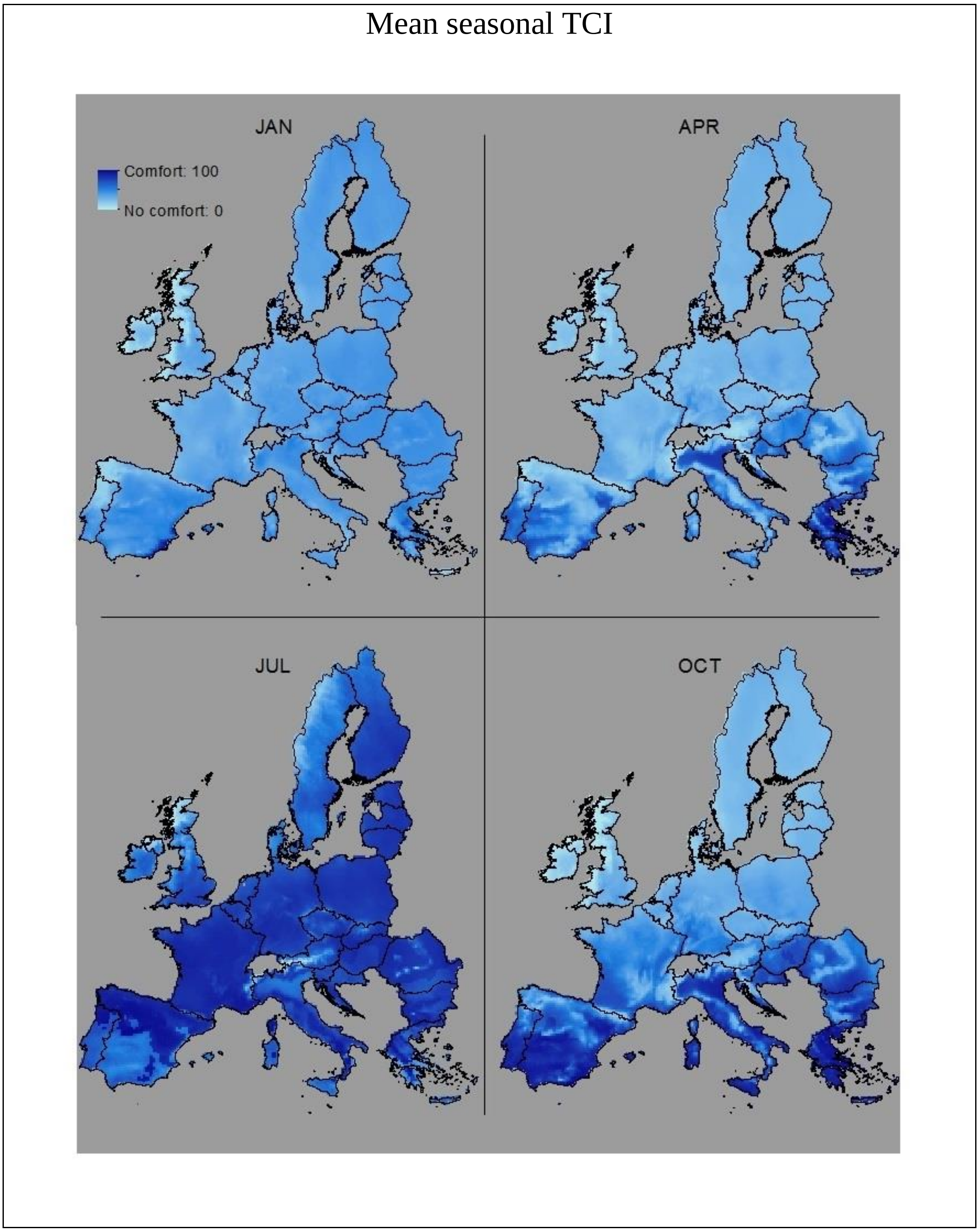

Figure 9. Mean seasonal TCI. The values have been linearly stretched (min/max).

It is evident how the climatic comfort changes with the seasons: In January it stays within comfortable levels only along the Mediterranean coastal areas of Spain and

Greece. In April, during the spring season, the climatic comfort levels are penetrating northward and toward the interior parts, most notably in northern Italy and essentially all of Greece. During the high summer period in July, most of Europe experiences high climatic comfort, except for mountainous/high elevation areas, and the now all too dry/hot southern areas of Spain and Portugal (and parts of the Greek isles). During the month of October, climatic comfort levels recede southward, while maintaining a good hold on Spain, Italy, Greece, and the Balkans. In a reversal, southern Spain and Portugal has now once more become comfortable. The TCI model thus predicts what we already would expect.

The corresponding mean for the entire year is shown in Figure 10.

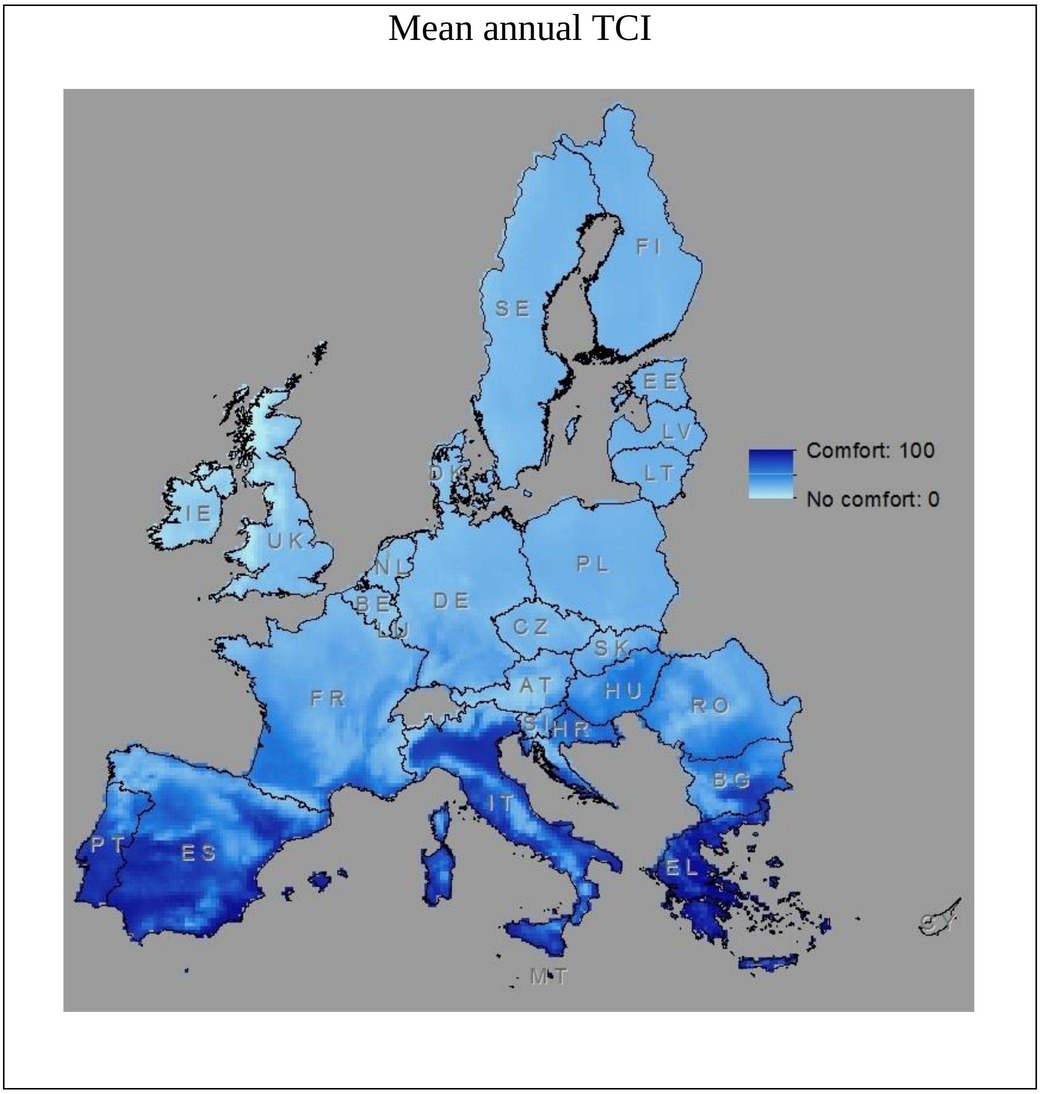

Figure 10. Mean annual TCI. The values have been linearly stretched (min/max).

The spatial distribution of climatic well-being is, not unsurprisingly, consistent with latitude and major elevations. The highest mean, annual comfort levels are found around the Mediterranean coastal areas, as well as the highest number of annual sunshine hours (Figure 19). Areas of low year-round comfort are found particularly in the northern and western parts of Ireland and the UK.

4.2 Combined socioeconomic and climatic QoL levels

The results of the three different methods (weighted sum, fuzzy AND, and arithmetic mean) of combining the socioeconomic and climatic comfort factors are presented here. The model cell values range from 0 (lowest) to 1 (highest), and have been multiplied by a factor of 10 in Table 10.

The 2014 (observed) and 2020 (projected) weighted sum Quality of Life (QoL) results are shown in Figure 11, together with their difference (2014 subtracted from 2020).

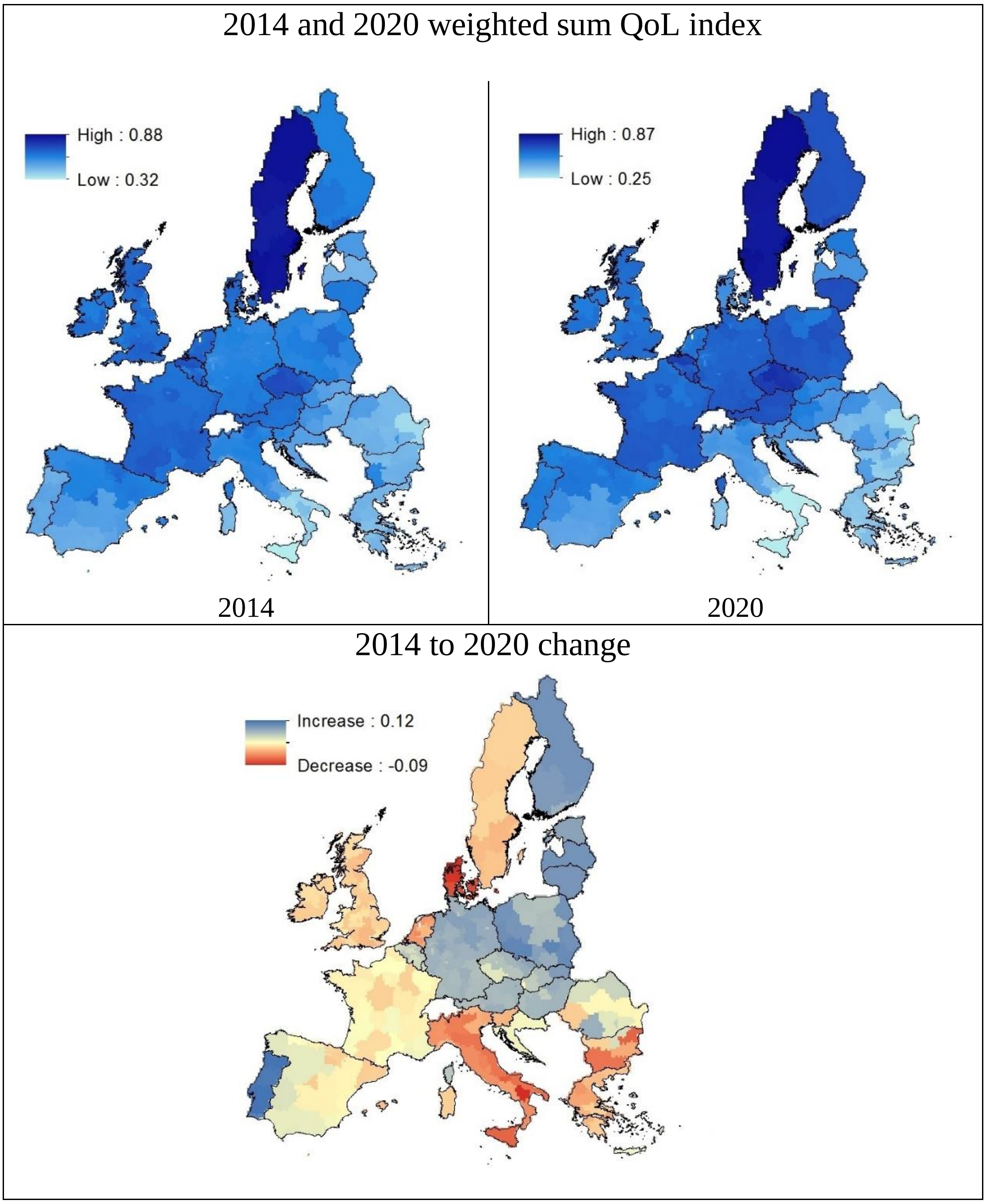

Figure 11. 2014 and 2020 weighted sum QoL index, and change 2014 to 2020. The values have been stretched using 2.5 standard deviations.

Ranking highest in 2014 (see Table 10) is Sweden with a country mean of 8.6; ranking lowest is Sicily with a regional mean of 3.3. The distribution indicates that most of Western and Northern Europe is faring well, whereas southern Italy and parts of Eastern Europe are struggling in terms of national well-being, in particular eastern Romania (regional mean of 3.7). Other parts of Eastern Europe are faring considerably better, most notably the Czech Republic (country mean of 7.0) and Poland (country mean of 6.0).

In 2020, Sweden has declined slightly but is still ranked the highest at 8.4. Denmark in particular is showing a -12.9% overall decline, from 6.5 to 5.7 on the index scale, mainly due to a substantial decrease in the important health indicator. In Southern Europe, Portugal in particular shows a remarkable overall +22.9% improvement, from 5.0 to 6.2, mainly due to improvements in the health and severe material deprivation indicators, whereas Spain and Greece both remain fairly constant. Southern Italy, however, shows a decline, dragging the national average down by -8.8%, from 5.2 to 4.7. Poland (+13.0%), the Czech Republic (+7.5%), and the Baltic states with Latvia (+19.5%) in the lead show great improvement.

The positive (blue) and negative (red) changes in weighted sum QoL levels between year 2014 and target year 2020 are shown at the bottom of Figure 11. This change in QoL levels is simply a cell-by-cell subtraction of the 2014 values from the 2020 values: The "Increase" and "Decrease" values represent the extremes (up/down) of the changes in cell values, and the figure is intended as a guide to more easily spot where changes are projected to take place, and their associated magnitudes.

The differential map more clearly indicates that the greatest negative changes between 2014 and 2020 are evident in Denmark, in southern Italy, and in eastern/southern Bulgaria. The greatest improvements are shown by Portugal, Finland, the Baltic states, and large portions of Eastern/Central Europe.

The projected percent change from 2014 to 2020 by country and socioeconomic theme is shown in Table 8.

Table 8. Projected % change 2014 to 2020 by country and socioeconomic theme.

NUTS ID	Health	Disp. inc.	Empl.	Mat. depr.	Edu.	Crime	Gen. gap	Inc. gap	Pov. risk	Early leav.	Price levels
AT	1.78	10.15	2.01	5.34	54.93	-100.00	-14.38	3.90	2.68	-23.14	2.11
BE	3.04	11.76	4.52	-1.83	-1.35	5.11	-23.02	-1.95	-3.62	-34.49	1.71
BG	-10.49	31.94	10.27	-30.71	25.70	37.97	-18.82	6.16	-20.74	17.36	10.58
CY	-0.12	7.92	-1.20	11.63	21.18	49.02	-62.22	3.68	4.43	-100.00	0.81
CZ	3.52	11.50	-0.99	-53.73	33.48	-99.28	-3.53	-2.68	-21.19	33.09	17.95
DE	1.15	14.29	3.20	6.98	7.96	6.48	-6.55	3.44	1.31	-21.05	-1.76
DK	-15.12	18.02	2.21	3.31	20.96	-12.96	-15.99	7.41	4.98	-35.51	-0.55
EE	3.43	23.75	1.97	-20.64	20.07	-53.99	-6.47	-8.40	-9.55	7.46	9.99
EL	-1.91	-3.07	10.38	18.78	46.72	50.49	-31.71	0.59	6.76	-81.89	3.00
ES	-0.09	4.21	14.90	8.05	-3.22	-28.53	-43.44	5.03	5.68	-42.83	3.02
FI	6.99	19.10	5.16	-37.28	-1.79	-49.53	-23.81	-1.37	-3.38	-6.11	-1.63
FR	-2.08	11.59	1.73	-6.77	13.99	10.09	0.00	7.99	-1.99	-54.44	-0.88
HR	-2.22	15.02	0.57	-1.01	34.50	0.79	0.00	-3.36	-11.06	-100.00	1.99
HU	5.14	10.65	-1.32	7.16	26.95	18.26	-11.48	-5.21	0.40	1.93	-2.40
IE	3.13	4.34	6.43	48.59	7.26	-47.85	-32.00	-6.95	20.07	-83.77	-3.69
IT	-10.64	7.07	7.04	44.23	29.96	-26.36	-9.96	-0.21	7.77	-30.87	-2.27
LT	5.55	20.94	-0.35	-46.06	33.68	-100.00	-45.80	0.65	-8.16	-45.08	11.33
LU	4.91	10.78	2.91	11.17	11.90	-26.89	-31.99	5.20	6.62	65.57	7.54
LV	1.76	15.03	3.04	-34.47	21.43	-17.96	-32.54	-4.20	-16.57	-26.71	14.79
MT	0.15	10.78	0.72	23.44	24.53	10.85	-32.16	2.72	12.80	-19.90	5.94
NL	-9.19	7.27	8.20	-5.40	17.19	23.53	-9.13	-5.10	-2.31	-15.86	2.72
PL	-4.04	26.63	1.89	-100.00	23.71	13.25	-0.98	-9.18	-59.56	-9.44	-3.01
PT	10.07	11.22	2.45	-6.56	25.46	-50.32	1.70	-9.35	-3.42	-79.83	-2.85
RO	-10.62	29.33	-4.86	-32.36	31.32	43.84	-10.00	-1.50	-13.81	8.78	1.99
SE	0.58	15.65	2.85	-100.00	9.78	-47.33	4.13	3.70	-1.67	4.18	3.54
SI	-9.36	9.21	3.02	10.06	20.20	35.43	-41.37	0.36	5.39	25.00	7.81
SK	-7.36	25.55	0.46	-75.94	31.38	-85.86	-10.96	-9.13	-40.45	42.99	15.90
UK	-1.82	-2.02	1.11	19.90	6.92	-68.46	-12.25	-4.78	-0.83	-50.85	5.12
EU28	-3.42	10.78	1.99	-3.05	15.28	-	-12.44	1.31	-0.51	-31.88	-

The fuzzy AND method result and the arithmetic mean method result are shown in Figure 12 for 2014 only (not projected into 2020).

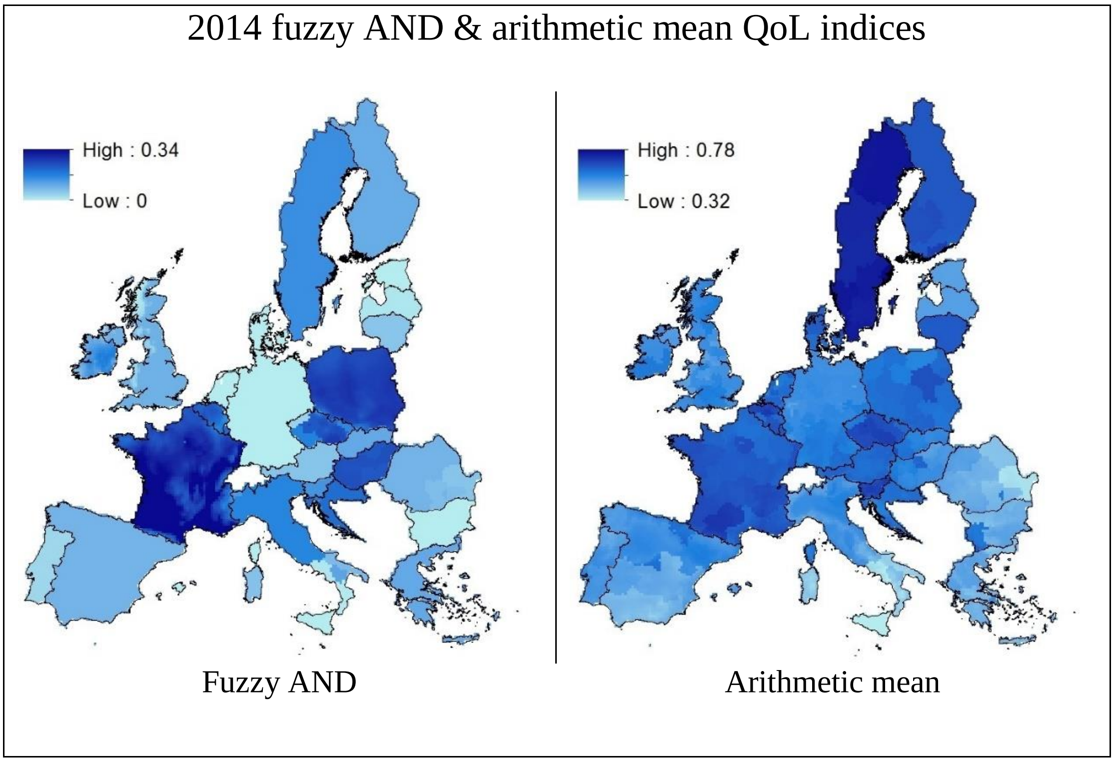

Figure 12. 2014 fuzzy AND & arithmetic mean QoL index. The values have been stretched using 2.5 standard deviations.

France and Germany/Denmark in particular stand out in the fuzzy AND distribution, with very high and very low QoL levels, respectively, whereas Sweden exhibits more middle-of-the-road levels. This minimizing QoL distribution is quite different (as shown in Table 9) from the 2014 weighted sum distribution of Figure 11.

The arithmetic mean distribution is much more similar to the weighted sum distribution, with Sweden, Lithuania, the Czech Republic, and France at the high end of the scale. At the low end, we once again find southern Italy and eastern Romania.

5 DISCUSSION

5.1 Spatial distribution of climatic well-being/comfort

The countries around the Mediterranean clearly benefit from its moderating influence, while also receiving the highest amount of sunshine (Seville, Spain is normally credited with the highest average number of annual sunshine hours in Europe, with 2917 for the 1981-2010 period (Agencia Estatal de Meteorología (AEMET) 2017); the number of annual hours estimated here (Section 3.2.1.3.3) is 2873). The region of high climatic comfort in northern Italy is notable: Most likely, it benefits from its proximity to the Mediterranean and from being nestled in the protective shadow of the Alps; topography as such has not been considered in this study, but low elevation is likely also a contributing factor. In contrast, it is evident that proximity to the Atlantic Ocean (e.g. western and northern Ireland and UK, and northwestern Spain) constitutes a source of too high levels of precipitation and wind (see Appendix B: Fuzzy memberships of climatic TCI factors), with the well-known exception of southwestern France, a popular retirement destination for sun starved Brits. During the summer months, a large portion of mainland Spain and Portugal also become too hot/dry for comfort.

5.2 Spatial distribution of combined climatic and socioeconomic well-being

The 2014 spatial distribution of combined (weighted sum) climatic and socioeconomic well-being (QoL) is shown in Figure 11. The differential map indicates that parts of Spain, Greece, and southern Italy will continue to feel the effects of the recent economic recession, in large part due to continued high unemployment levels (Sicily currently also grapples with high levels of poverty and material deprivation, and low levels of educational attainment), whereas Portugal will experience significant improvements. However, these projections are based on simple linear regression with low levels of confidence in these particular areas (Appendix D: Fuzzy memberships of socioeconomic factors and Appendix F: Country statistics (NUTS 0)).

Based on the 2020 QoL projection and subject to regression errors, Table 10 indicates that Portugal will experience the largest projected increase in life satisfaction (+22.9%), and that Denmark will experience the largest decrease (-12.9%) between 2014 and 2020. Table 8 indicates that possible causes of a Portuguese increase may be attributed to substantial improvements in the indicators rated most important (Table 11), i.e. health (+10.1%) and material deprivation (-6.6%); however, both of these indicators have low R^2 values and the projections should therefore be considered unreliable.

The "winner" in major well-being surveys has lately been Denmark, shown in Table 10, but here trailing Sweden with a country mean of 6.5. Possible causes of a Danish decline may be attributed to a substantial decrease in the important health indicator (-15.1%, with an R^2 value of 0.87).

The generally higher well-being levels of Western and particularly Northern Europe, may be attributed to the importance of the well-developed welfare state to life satisfaction, as described by Kotakorpi and Laamanen (2010).

5.3 Comparison of the three combination methods

Table 9 shows the extracted mean country (NUTS 0) QoL index values of the three different combination methods. The fuzzy AND overlay results are very unrealistic, whereas the arithmetic mean method clearly produces results reasonably close to those of the weighted sum method, with some exceptions. The weighted sum method is clearly the best method of the three, as it allows for individual factor weighting and development of scenarios.

Table 9. Comparison of three combination methods of mean country QoL levels.

NUTS ID	2014 weighted sum	2014 fuzzy AND	% diff. from weighted sum	2014 arithmetic MEAN	% diff. from weighted sum
AT	6.45	0.60	-90.66	6.13	-4.95
BE	6.71	2.08	-69.03	6.51	-3.02
BG	4.92	0.00	-100.00	4.99	1.34
CY	No Data	No Data	No Data	No Data	No Data
CZ	7.01	1.90	-72.82	6.53	-6.76
DE	6.05	0.00	-100.00	5.60	-7.53
DK	6.52	0.00	-100.00	6.21	-4.73
EE	5.44	0.00	-100.00	5.17	-4.99
EL	4.64	1.04	-77.64	4.81	3.73
ES	5.66	0.84	-85.12	5.07	-10.30
FI	6.16	1.01	-83.69	6.44	4.45
FR	6.66	2.92	-56.10	6.47	-2.89
HR	5.22	1.98	-62.10	4.87	-6.85
HU	5.19	2.35	-54.75	5.52	6.24
IE	6.36	1.26	-80.26	5.65	-11.23
IT	5.20	1.22	-76.55	5.99	15.32
LT	6.27	0.57	-90.98	6.32	0.80
LU	6.82	1.99	-70.86	6.04	-11.37
LV	4.67	0.09	-97.98	6.46	38.26
MT	7.38	0.52	-92.90	6.35	-14.02
NL	6.65	0.00	-100.00	5.12	-22.98
PL	6.05	2.59	-57.16	6.08	0.52
PT	5.02	0.30	-93.99	7.49	49.19
RO	4.63	0.79	-83.00	4.62	-0.27
SE	8.56	1.48	-82.71	5.26	-38.56
SI	5.91	1.38	-76.63	5.75	-2.76
SK	5.36	1.06	-80.33	6.79	26.67
UK	6.53	0.79	-87.93	5.48	-16.08

5.4 Comparison of weighted sum country results with survey results

Figure 13 and Table 10 show a country-by-country comparison between the 2014/2020 weighted sum Multi-Criteria Evaluation (MCE) model result and the results from the 2013 EU-SILC survey (Eurostat 2015), Eurostat data table "ilc_pw01", and the 2014 OECD survey (OECD 2016) of OECD member countries.

Survey QoL levels ("mean life satisfaction") are measured on an 11 point scale, with 10 being the highest. MCE country means have been extracted and calculated on a cell by cell basis using Geographic Information Systems (GIS), and have been multiplied by a factor of 10 to enable direct comparison.

MCE model vs. country survey results

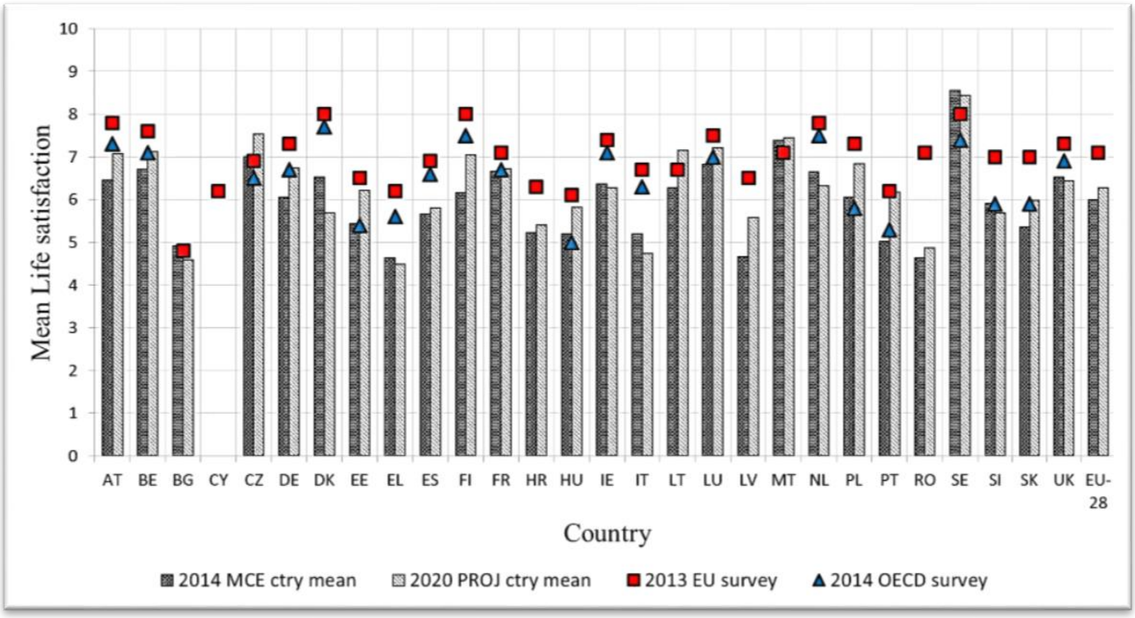

Figure 13. Country comparison of mean life satisfaction. 2014 and 2020 weighted sum MCE vs. 2013 EU and 2014 OECD surveys.

A very good agreement between the 2014 MCE model result and the survey results is found for Bulgaria, the Czech Republic, Luxembourg, and France, which may indicate that the specific selection of themes and/or weights reflect the prevailing national attitudes and priorities of these countries more closely.

Figure 13 and Figure 14 indicate that the results of the MCE analysis fairly consistently (with one notable exception) underestimates the EU survey results (Romania in particular), whereas they are more in line with the OECD results. Barring major changes in well-being levels between 2013 and 2014, this may indicate that the analysis more closely reflects how the OECD measures well-being than the EU.

However, the regression lines, with associated R^2 values (2013 EU ≈ 0.46, 2014 OECD ≈ 0.53), of Figure 14 reveal some additional structure indicating that the MCE model underestimation is more pronounced at the lower end of the QoL scale, and less pronounced (or even reversed) at the upper end, i.e. a tipping point is indicated where countries with generally lower objective QoL levels display higher subjective

QoL levels, and countries with generally higher objective QoL levels display lower subjective QoL levels (a point of "diminishing objective QoL returns").

Statistical correlation: 2014 MCE country means vs. 2013 EU and 2014 OECD surveys

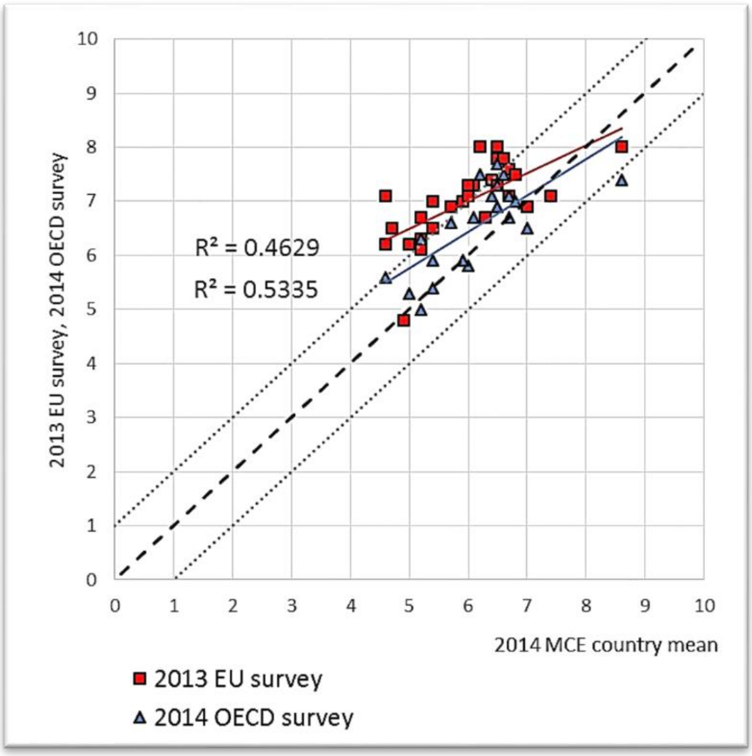

Figure 14. Statistical correlation between 2014 MCE country means and the 2013 EU and 2014 OECD surveys. Solid lines indicate survey regression, with associated R^2 values, and the dashed line indicates unity. MCE estimated error interval of +/- 10% shown using dashed grey lines.

The notable exception mentioned above is Sweden, where the MCE model result is actually higher than either survey result, possibly indicating a bias on the part of the author during weight selection (possibly an overly high emphasis on the health aspect).

On the other hand, the overestimation might indicate that, due to author bias, the factor and weight selections are particularly well suited to Sweden, with the result thus more accurately reflecting a lowered subjective well-being contribution (Swedes should perhaps be objectively happier than they are?).

Sweden is undoubtedly a prosperous country and Huppert et al. (2009), in their discussion of the results of the ESS Well-being Module, note the increasing importance of subjective factors to overall well-being levels in economically developed nations, with mounting evidence of generally increasing levels of depression, divorce, and suicide being associated with increasing rates of prosperity. They also found that Denmark, second only to Norway, went against this general trend with among the lowest levels of depression in Europe, which might partly explain the MCE underestimation (Danes should perhaps be objectively less happy than they are?).

The difference between the MCE model result and the survey results may then indicate the following (not mutually exclusive):

a) It may simply be an expression of varying cultural and national valuations of what is important, i.e. a difference in the way objective themes should be selected and/or weights assigned in the different countries.
b) It may indicate the strength of the subjective well-being contribution to overall well-being levels, at different levels of objective well-being (assuming the model is correct).

Table 10. Country comparison of mean life satisfaction on an 11 point scale (0-10).

NUTS ID	2013 EU survey	2014 OECD survey	2014 MCE country mean	2020 PROJ country mean	2014-2020 change (%)
AT	7.8	7.3	6.5	7.1	9.60
BE	7.6	7.1	6.7	7.1	6.16
BG	4.8	No Data	4.9	4.6	-6.83
CY	6.2	No Data	No Data	No Data	No Data
CZ	6.9	6.5	7.0	7.5	7.52
DE	7.3	6.7	6.1	6.7	11.21
DK	8.0	7.7	6.5	5.7	-12.89
EE	6.5	5.4	5.4	6.2	14.34
EL	6.2	5.6	4.6	4.5	-3.27
ES	6.9	6.6	5.7	5.8	2.59
FI	8.0	7.5	6.2	7.1	14.44
FR	7.1	6.7	6.7	6.7	0.98
HR	6.3	No Data	5.2	5.4	3.58
HU	6.1	5.0	5.2	5.8	12.11
IE	7.4	7.1	6.4	6.3	-1.22
IT	6.7	6.3	5.2	4.7	-8.79
LT	6.7	No Data	6.3	7.2	14.10
LU	7.5	7.0	6.8	7.2	5.67
LV	6.5	No Data	4.7	5.6	19.48
MT	7.1	No Data	7.4	7.5	0.91
NL	7.8	7.5	6.6	6.3	-4.85
PL	7.3	5.8	6.0	6.8	13.04
PT	6.2	5.3	5.0	6.2	22.90
RO	7.1	No Data	4.6	4.9	5.35
SE	8.0	7.4	8.6	8.4	-1.40
SI	7.0	5.9	5.9	5.7	-3.94
SK	7.0	5.9	5.4	6.0	11.45
UK	7.3	6.9	6.5	6.4	-1.47
EU-28	7.1	No Data	6.0	6.3	4.54

5.5 The importance of climate to well-being

As shown by the final factor weighting in Table 11, the importance of (a static) climate to well-being is here rated very low, at only slightly more than 3%, compared to most of the socioeconomic factors under consideration; only income gap, early leavers, and gender gap are rated lower. A weighted sum combination of socioeconomic factors only was also generated; however, no discernable difference could be seen compared to Figure 11, and the result was therefore not included here.

Table 11. Weight assignments in decreasing order of importance.

FACTOR	%
Healthy Life Years	21.02
Severe material deprivation	17.19
Employment	16.37
Crime	10.42
Poverty/social exclusion risk	9.19
Disposable income	8.47
Higher education	4.32
Price levels	4.06
Climate	3.14
Income gap	2.95
Early leavers	1.76
Gender gap	1.11

Even with considerable changes to how the weight assignment is performed, i.e. how climate is rated against all the other factors, it seems unlikely that climatic comfort would become substantially more prominent. An explanation of this low relative importance might be that, in the grand scheme of things, climatic comfort is either considered a luxury you cannot do much about (to those who live in colder climates) or something taken for granted (to those who live in warmer climates). In other words, a static climate is simply something one has to deal with in everyday life and, short of moving somewhere else, it cannot be changed. Naturally, the importance of climate varies as a matter personal preference, likely as a normal distribution.

5.6 Sources of error and limitations of the study

The main sources of error in the construction of the climatic comfort index are most likely the fuzzy membership functions chosen, and the TCI weighting scheme, not the underlying climatic data or the Universal Thermal Climate Index (UTCI) calculation.

The main sources of error in the construction of the combined well-being index are most likely the individual factor weight assignments, together with the selection or omission of socioeconomic themes; Ordinary Least Squares (OLS) regression analysis indeed indicates that some explanatory variables are missing from the model (ref. to Appendix H: Exploratory Regression and OLS regression), and use of additional socioeconomic themes either omitted here, such as the degree of urbanization, or not available long-term, would likely alter the QoL distribution somewhat. Still, the (global) regression analysis indicates that the 12 model factors are statistically significant (with the exception of price levels) and non-redundant, and that the 12 factor model, given appropriate weighting, manages to explain about 78% of the 2013 EU survey result.

The choice of a purely linear fuzzy membership function as descriptor of the socioeconomic indicators may also warrant further investigation (e.g. the correspondence between disposable income and well-being may not be linear, exhibiting diminishing marginal utility).

In terms of overall errors, it seems clear that the accuracy of the climatic and socioeconomic data is of less importance than either the selection, weighting, or combination of the different factors (an estimated overall MCE error interval of +/-10% is shown in Figure 14). As concluded by Decancq and Lugo (2012), in particular the weighting is crucial and remains a subjective choice.

In forecasting the socioeconomic data, the simple linear regression method does not suffice as many of the indicators exhibit non-linearity (although many do not). It is suggested that a more sophisticated regression method (outside the scope of this study) be employed, which accurately predicts where the indicators of each country are trending.

There will likely always be a gap between subjective well-being and objective (model) well-being, which analysis of objective factors alone will not be able to bridge; however, using a more precise factor selection in combination with a more precise factor weighting, the proposed model should be able to establish an objective baseline and help isolate the subjective well-being contribution.

This page intentionally left blank

6 CONCLUSIONS

Based on the results presented, the proposed model seems able to fairly closely estimate actual well-being levels from objective, quantitative country statistics. Fit discrepancies may indicate the absence of a subjective well-being dimension, in addition to the objective dimensions analyzed by the model.

The varying levels of fit between the model and survey results observed from country to country also suggest that this type of analysis ideally should be applied to a more homogeneous population than that of the entire EU-28, i.e. tailored to the prevailing attitudes and priorities of each individual member country or region. This flexibility in the assignment of weights is also considered the main strength of the model, and it should be possible to calibrate the weights, using a test and reference population.

In terms of forecasting, the author sees no reason why future well-being levels could not be predicted if a more sophisticated regression method is used.

Based on the model results, the weighted sum clearly is the most realistic factor combination method. This is of course not unexpected as the factors used in this analysis clearly cannot be of equal importance, which Decancq and Lugo (2012) agree with. It would also be unrealistic to expect that minima (fuzzy AND method) could reflect reality.

A somewhat unexpected conclusion based on the proposed model is that (a static) climate seems to play less of a role than we might think, compared to most of the selected socioeconomic factors; factor regression analysis even indicates a possibly negative correlation with EU-28 well-being levels.

This page intentionally left blank

References

Abdallah, S., S. Thompson, and N. Marks. 2008. METHODS: Estimating worldwide life satisfaction. *Ecological Economics,* 65**:** 35-47. DOI: 10.1016/j.ecolecon.2007.11.009

Agencia Estatal de Meteorología (AEMET). 2017. Standard Climate Values. Sevilla Aeropuerto. Retrieved 04 January 2017, from http://www.aemet.es

ASHRAE. 2004. *ANSI/ASHRAE standard 55-2004 : Thermal environmental conditions for human occupancy*. Atlanta : ASHRAE, 2004.

Błażejczyk, K., and A. Błażejczyk. 2014. Assessment of bioclimatic variability on regional and local scales in central Europe using UTCI. *Scientific Annals of "Alexandru Ioan Cuza" University of Iasi,* LX**:** 67-82.

Blazejczyk, K., Y. Epstein, G. Jendritzky, H. Staiger, and B. Tinz. 2012. Comparison of UTCI to selected thermal indices. *Int J Biometeorol,* 56**:** 515-535. DOI: 10.1007/s00484-011-0453-2

Błażejczyk, K., G. Jendritzky, P. Bröde, D. Fiala, G. Havenith, Y. Epstein, A. Psikuta, and B. Kampmann. 2013. An introduction to the Universal Thermal Climate Index (UTCI). *Geographia Polonica,* 86**:** 5-10. DOI: 10.7163/GPol.2013.1

Brereton, F., J. P. Clinch, and S. Ferreira. 2008. Happiness, geography and the environment. *Ecological Economics,* 65**:** 386-396. DOI: 10.1016/j.ecolecon.2007.07.008

Bröde, P., D. Fiala, K. Błażejczyk, I. Holmér, G. Jendritzky, B. Kampmann, B. Tinz, and G. Havenith. 2012. Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). *International Journal of Biometeorology,* 56**:** 481-494. DOI: 10.1007/s00484-011-0454-1

de Freitas, C. R., and E. A. Grigorieva. 2015. A comprehensive catalogue and classification of human thermal climate indices. *Int J Biometeorol,* 59**:** 109-120. DOI: 10.1007/s00484-014-0819-3

de Freitas, C. R., and E. A. Grigorieva. 2016. A comparison and appraisal of a comprehensive range of human thermal climate indices. *International Journal of Biometeorology***:** 1-26. DOI: 10.1007/s00484-016-1228-6

Decancq, K., and M. A. Lugo. 2012. Weights in Multidimensional Indices of Wellbeing: An Overview. *Econometric Reviews,* 32**:** 7-34. DOI: 10.1080/07474938.2012.690641

Eurofound. 2013. *Third European Quality of Life Survey - Quality of life in Europe: Subjective well-being*. Luxembourg: Publications Office of the European Union.

European Commission. 2010. Europe 2020 - A strategy for smart, sustainable and inclusive growth. 35. Brussels.

European Commission. 2016. Eurostat - your key to European statistics. Retrieved 14 November 2016, from http://ec.europa.eu/eurostat

European Union (2004) Treaty establishing a Constitution for Europe. *Official Journal of the European Union,* C 310. http://eur-lex.europa.eu (last accessed 1 February 2017).

Eurostat, 2013. 2013 SILC module on well-being - Assessment of the implementation. Report.

Eurostat. 2015. *Quality of life - Facts and views*. Luxembourg: Publications Office of the European Union.

Eurostat. 2016. *Analytic report on subjective well-being*. Luxembourg: Publications Office of the European Union.

Eurostat Task Force on multidimensional measurement of quality of life, 2011. Multidimensional measurement of the quality of life. Report.

Fanger, P. O. 1970. *Thermal comfort : analysis and applications in environmental engineering*. Copenhagen : Danish Technical Press, 1970.

Fiala, D., J. K. Lomas, and M. Stohrer. 2001. Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. *International Journal of Biometeorology,* 45**:** 143-159. DOI: 10.1007/s004840100099

Forsythe, W., E. Rykiel, R. Stahl, H.-i. Wu, and R. Schoolfield. 1995. A model comparison for daylength as a function of latitude and day of year. *Ecological Modeling,* 80**:** 87-95.

Ge, Q., Q. Kong, J. Xi, and J. Zheng. 2016. Application of UTCI in China from tourism perspective. *Theoretical and Applied Climatology***:** 1-11. DOI: 10.1007/s00704-016-1731-z

Havenith, G., D. Fiala, K. Błazejczyk, M. Richards, P. Bröde, I. Holmér, H. Rintamaki, Y. Benshabat, et al. 2012. The UTCI-clothing model. *International Journal of Biometeorology,* 56**:** 461-470. DOI: 10.1007/s00484-011-0451-4

Höppe, P. 1999. The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. *International Journal Of Biometeorology,* 43**:** 71-75.

Houghten, F. C., and C. Yaglou. 1923. Determining lines of equal comfort. *ASHVE Transactions,* 29**:** 163-176.

Huppert, F. A., N. Marks, A. Clark, J. Siegrist, A. Stutzer, J. Vittersø, and M. Wahrendorf. 2009. Measuring Well-Being across Europe: Description of the ESS Well-Being Module and Preliminary Findings. 301. Springer.

Jendritzky, G., R. de Dear, and G. Havenith. 2012. UTCI--why another thermal index? *Int J Biometeorol,* 56**:** 421-428. DOI: 10.1007/s00484-011-0513-7

Kotakorpi, K., and J.-P. Laamanen. 2010. Welfare State and Life Satisfaction: Evidence from Public Health Care. *Economica,* 77**:** 565-583. DOI: 10.1111/j.1468-0335.2008.00769.x

Kovács, A., and J. Unger. 2014. Modification of the Tourism Climatic Index to Central European climatic conditions - examples. *Quarterly Journal of the Hungarian Meteorological Service,* 118**:** 147-166.

Lin, T. P., and A. Matzarakis. 2008. Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. *Int J Biometeorol,* 52**:** 281-290. DOI: 10.1007/s00484-007-0122-7

Maddison, D., and K. Rehdanz. 2011. The impact of climate on life satisfaction. *Ecological Economics,* 70**:** 2437-2445. DOI: 10.1016/j.ecolecon.2011.07.027.

Matzarakis, A., H. Mayer, and M. G. Iziomon. 1999. Applications of a universal thermal index: physiological equivalent temperature. *International Journal of Biometeorology,* 43**:** 76-84. DOI: 10.1007/s004840050119

Mayer, H., and P. Höppe. 1987. Thermal comfort of man in different urban environments. *Theoretical & Applied Climatology,* 38**:** 43.

Mieczkowski, Z. 1985. THE TOURISM CLIMATIC INDEX: A METHOD OF EVALUATING WORLD CLIMATES FOR TOURISM. *Canadian Geographer / Le Géographe canadien,* 29**:** 220-233. DOI: 10.1111/j.1541-0064.1985.tb00365.x

New, M., D. Lister, M. Hulme, and I. Makin. 2002. A high-resolution data set of surface climate over global land areas. *Climate Research,* 21**:** 1-25.

OECD. 2016. OECD.Stat Regional Well-Being. Retrieved 18 November 2016, from http://stats.oecd.org

Rehdanz, K., and D. Maddison. 2005. Climate and happiness. *Ecological Economics,* 52**:** 111-125. DOI: 10.1016/j.ecolecon.2004.06.015

Saaty, T. 1980. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. New York: McGraw-Hill.

Schubert, P. 2004. Cultivation Potential in Hambantota District, Sri Lanka. 76. Lund: Lund University.

Stiglitz, J. E., A. Sen, and J.-P. Fitoussi, 2009. Report by the Commission on the Measurement of Economic Performance and Social Progress. Commission Report, Paris.

T., M., T. R. Carter, P. Jones, and M. Hulme. 2004. A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). In *Tyndall Centre Working Paper 55*.

This page intentionally left blank

Appendix A: NUTS 0 classification codes and country names

NUTS ID	LATIN NAME
AT	ÖSTERREICH / AUSTRIA
BE	BELGIQUE-BELGIË / BELGIUM
BG	BULGARIA
CY	KÝPROS / CYPRUS
CZ	CESKÁ REPUBLIKA / CZECH REPUBLIC
DE	DEUTSCHLAND / GERMANY
DK	DANMARK / DENMARK
EE	EESTI / ESTONIA
EL	ELLADA / GREECE
ES	ESPAÑA / SPAIN
FI	SUOMI / FINLAND
FR	FRANCE
HR	HRVATSKA / CROATIA
HU	MAGYARORSZÁG / HUNGARY
IE	IRELAND
IT	ITALIA / ITALY
LT	LIETUVA / LITHUANIA
LU	LUXEMBOURG
LV	LATVIJA / LATVIA
MT	MALTA
NL	NEDERLAND / NETHERLANDS
PL	POLSKA / POLAND
PT	PORTUGAL
RO	ROMÂNIA / ROMANIA
SE	SVERIGE / SWEDEN
SI	SLOVENIJA / SLOVENIA
SK	SLOVENSKO / SLOVAKIA
UK	UNITED KINGDOM

Appendix B: Fuzzy memberships of climatic TCI factors

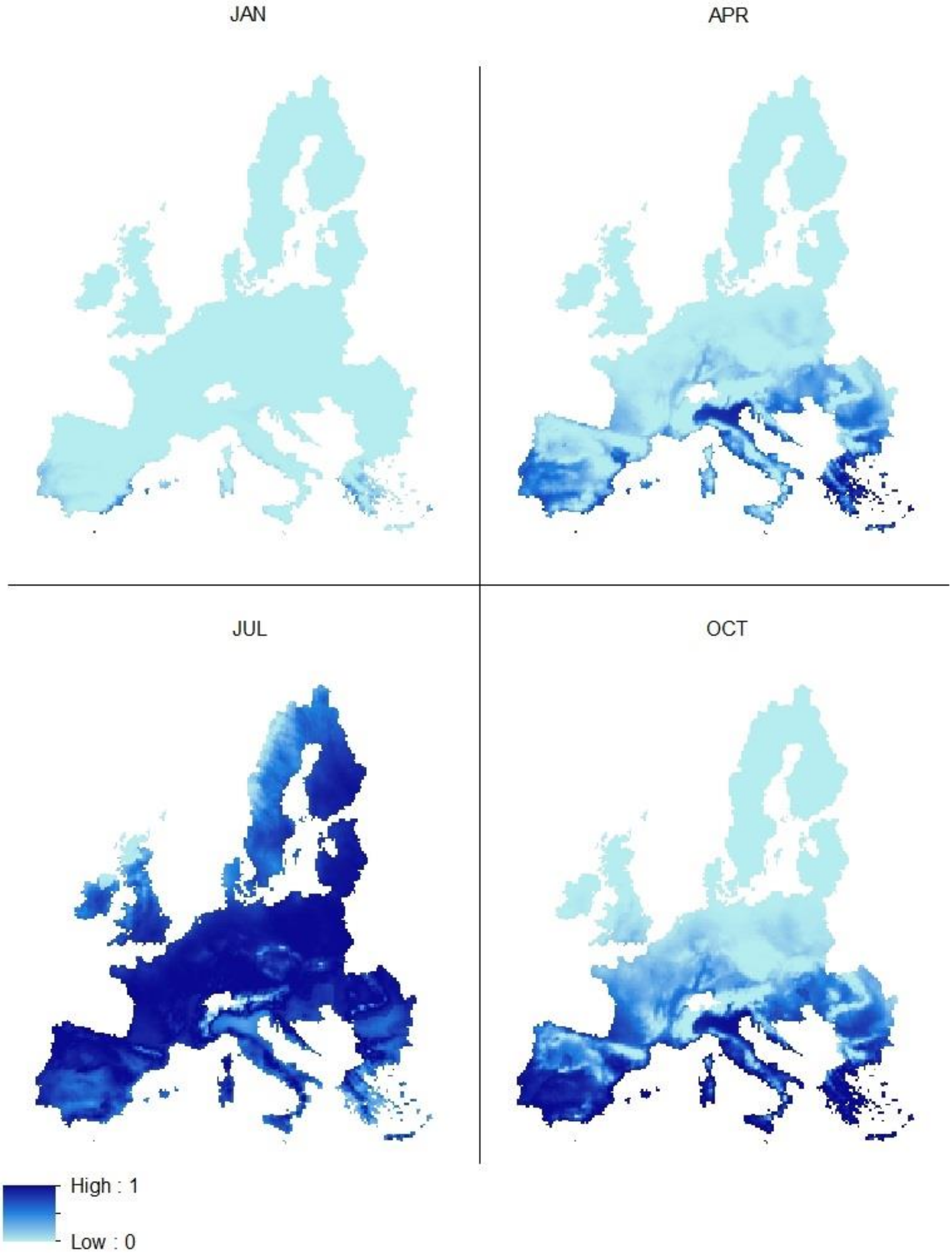

Figure 15. EU-28 PPS mean, monthly fuzzy membership.

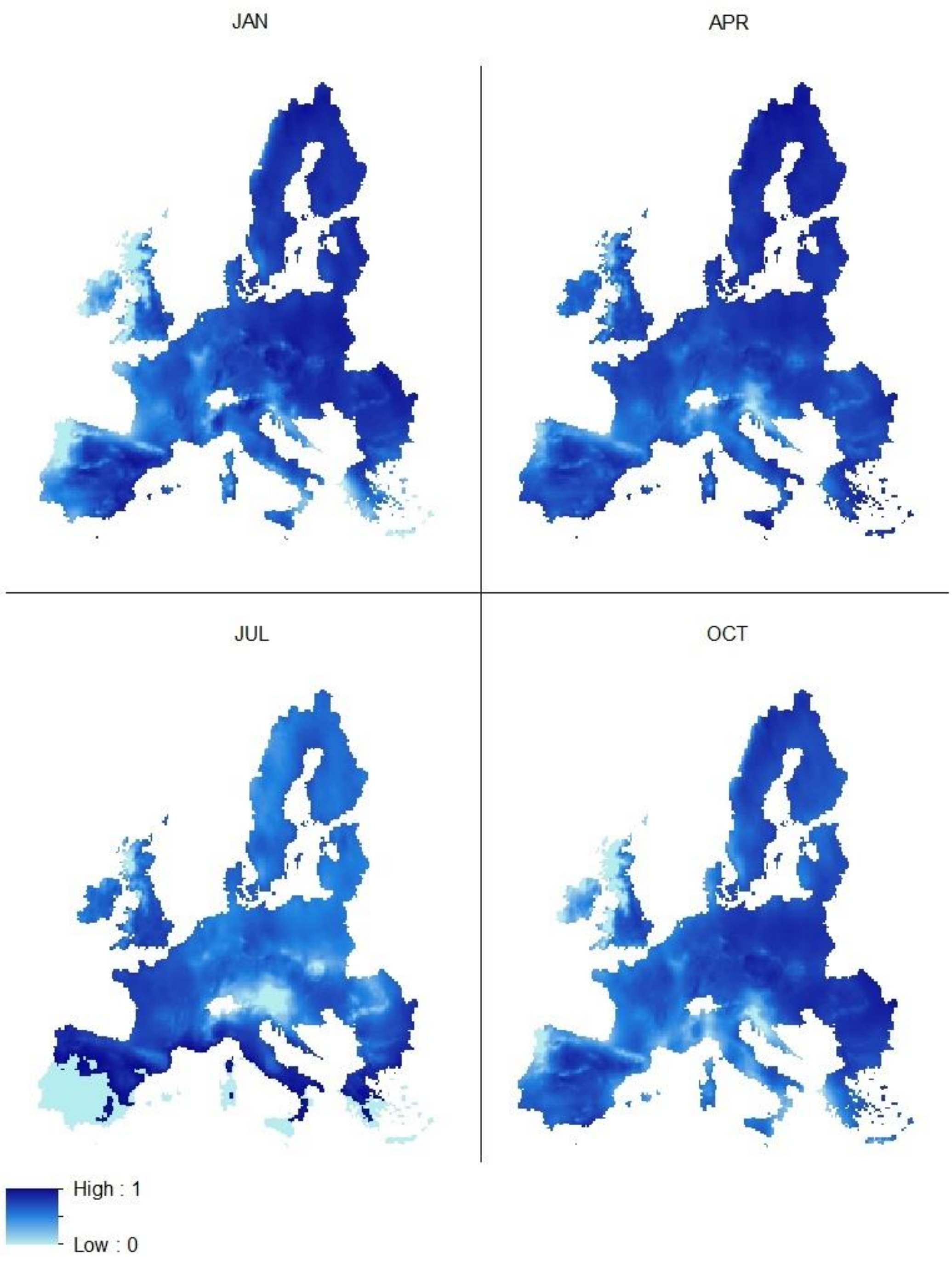

Figure 16. EU-28 Precipitation mean, monthly fuzzy membership.

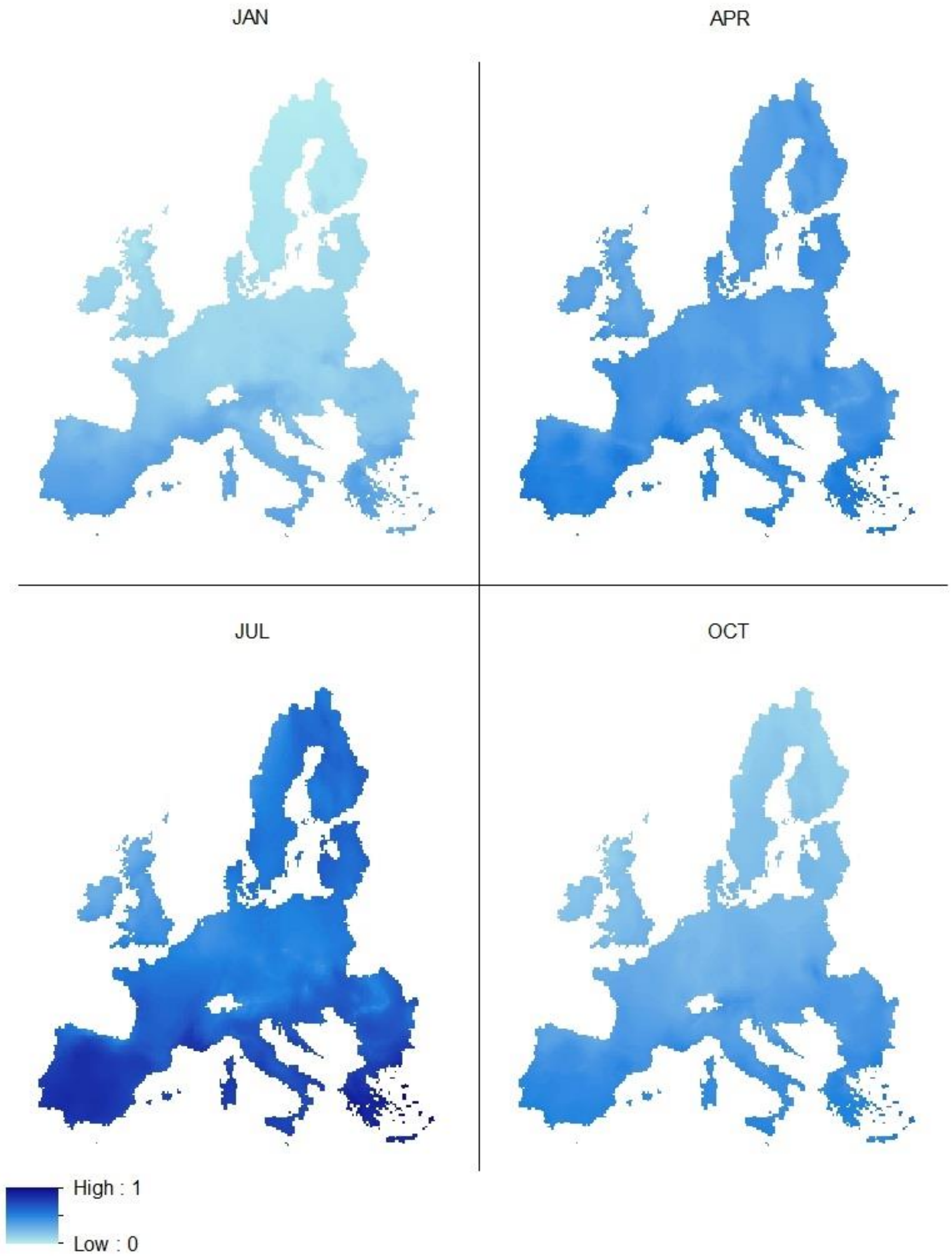

Figure 17. EU-28 Sunshine hours mean, monthly fuzzy membership.

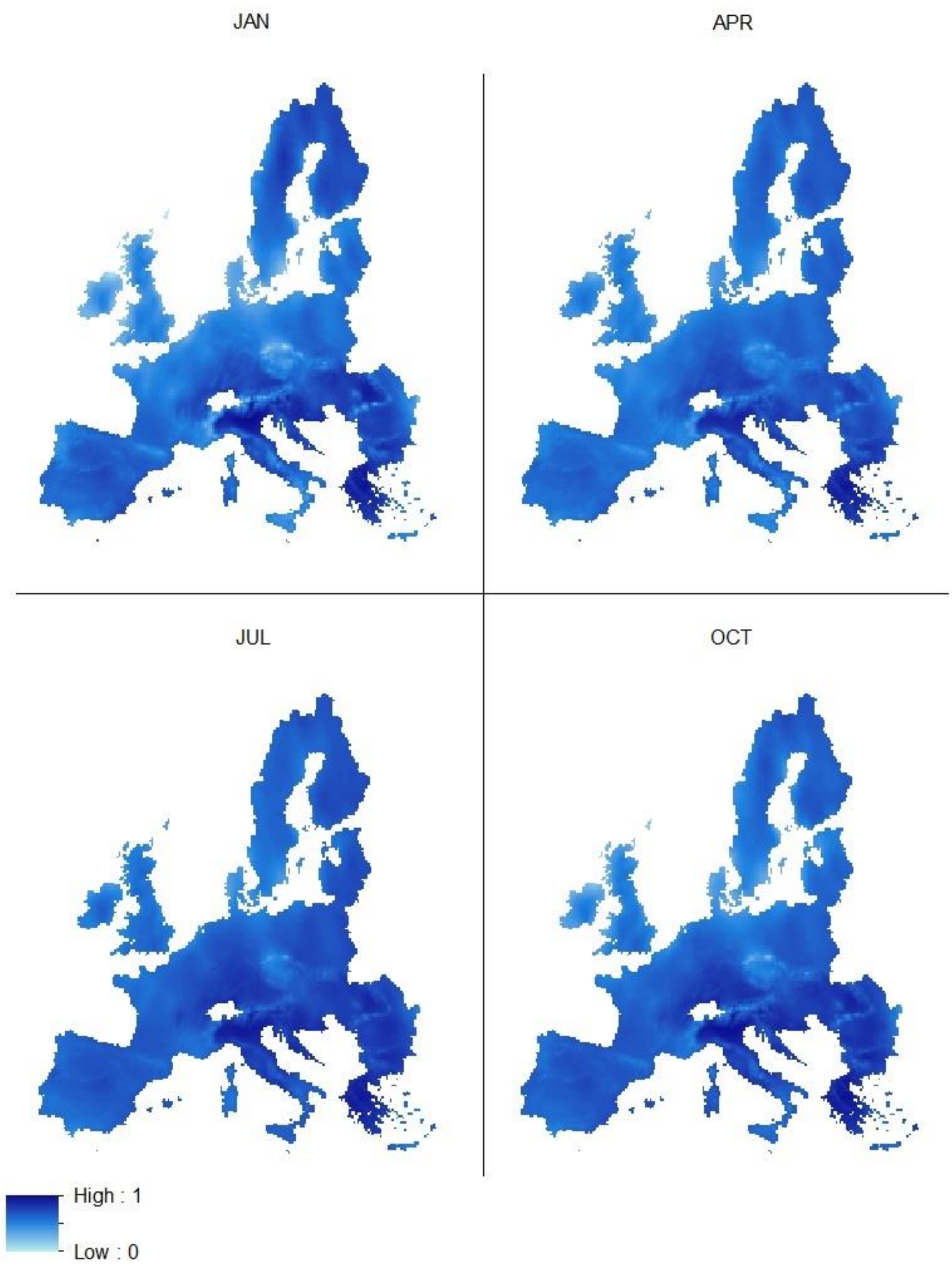

Figure 18. EU-28 Wind speed mean, monthly fuzzy membership.

Appendix C: Mean, annual total sunshine hours

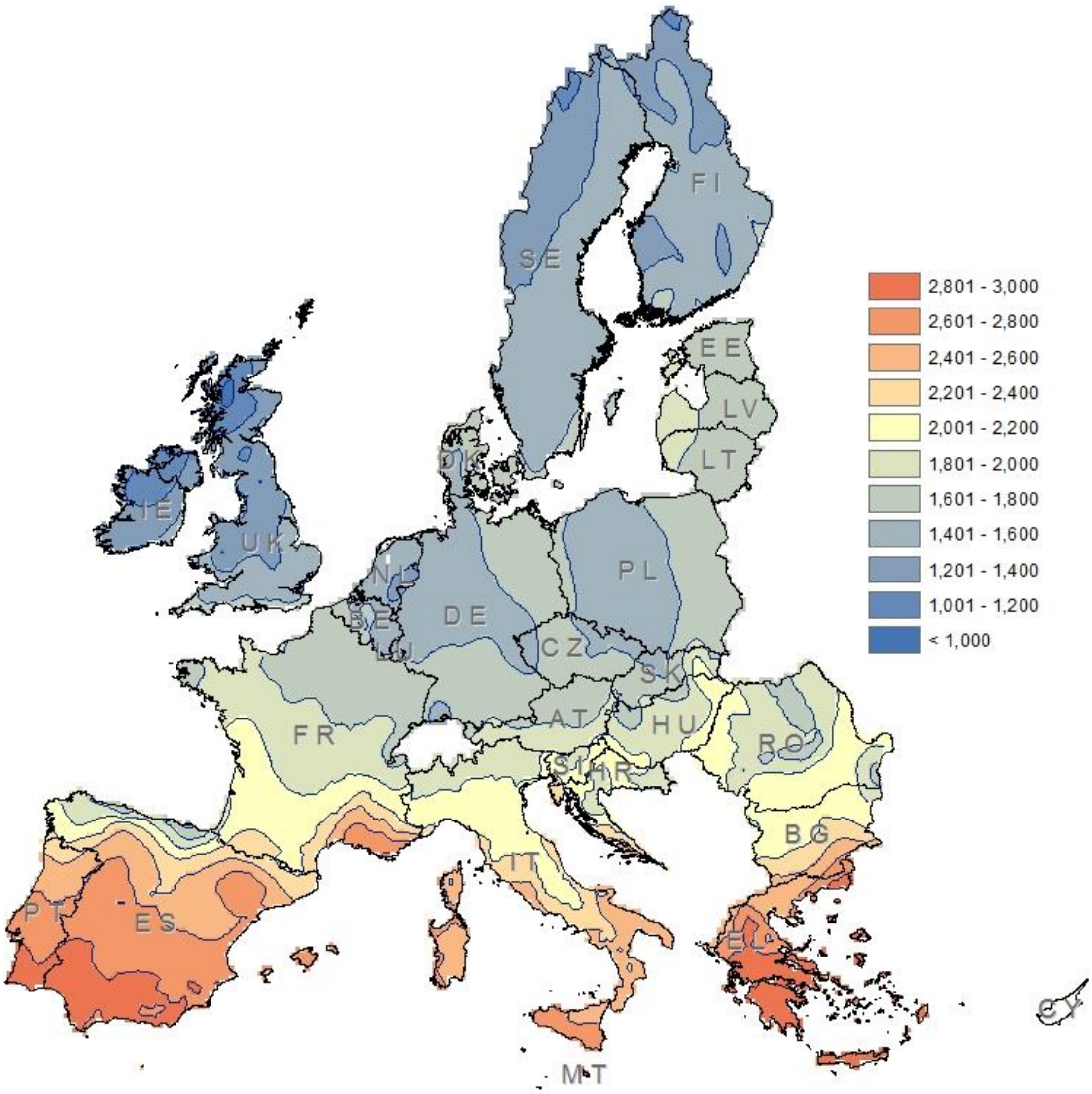

Figure 19. EU-28 mean, annual total sunshine hours.

Appendix D: Fuzzy memberships of socioeconomic factors

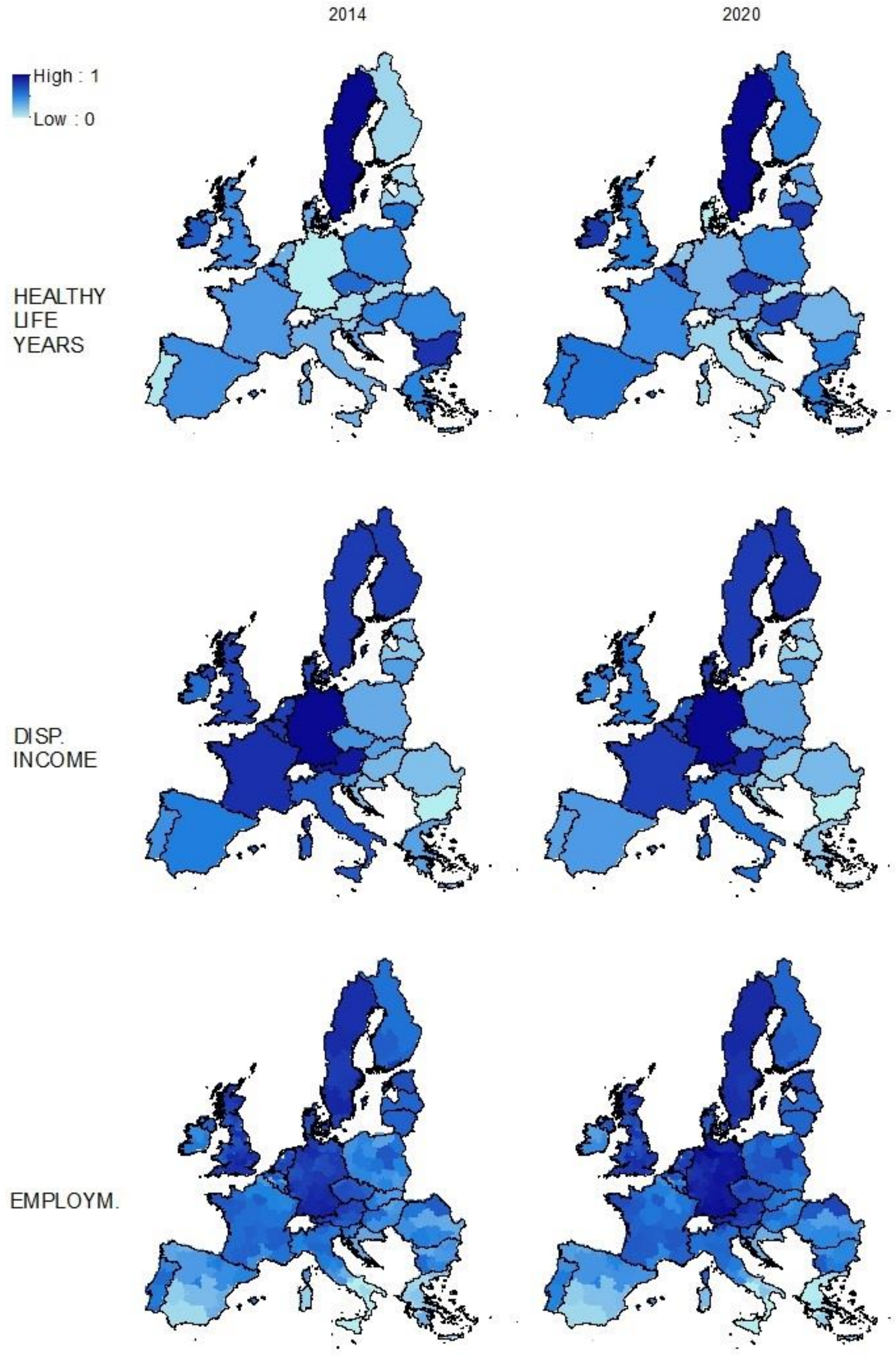

Figure 20. EU-28 fuzzy socioeconomic membership - part A.

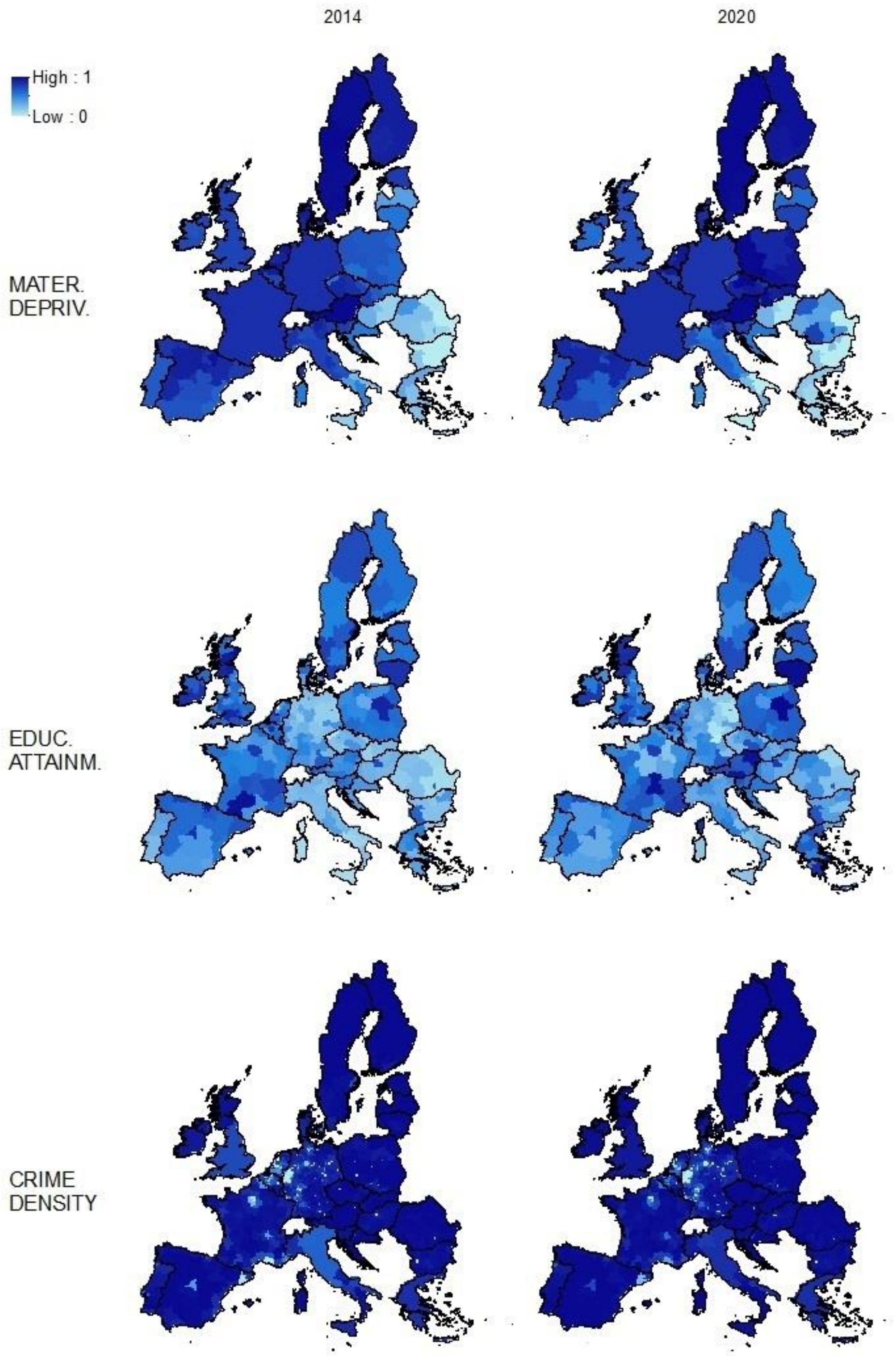

Figure 21. EU-28 fuzzy socioeconomic membership - part B.

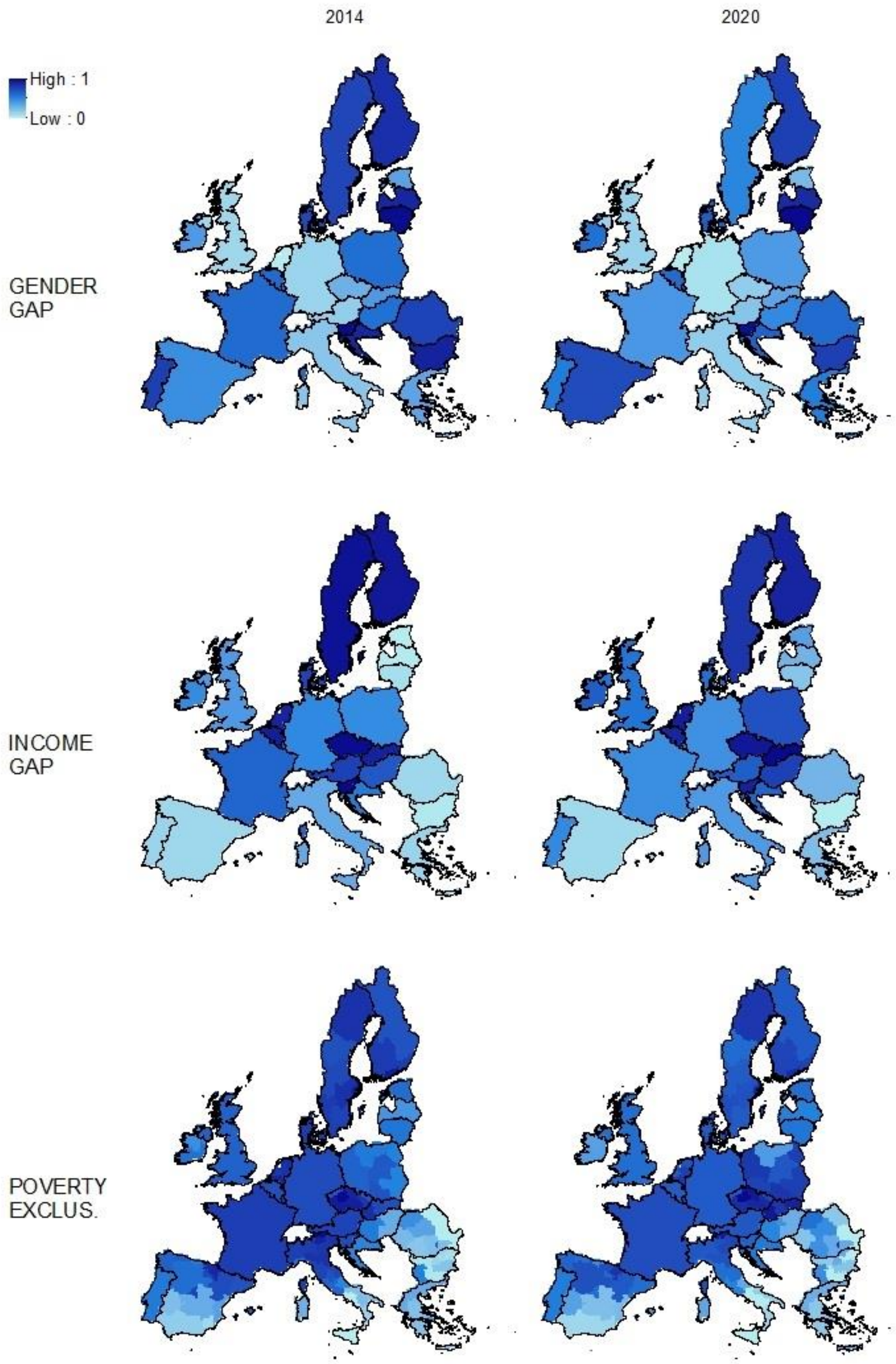

Figure 22. EU-28 fuzzy socioeconomic membership - part C.

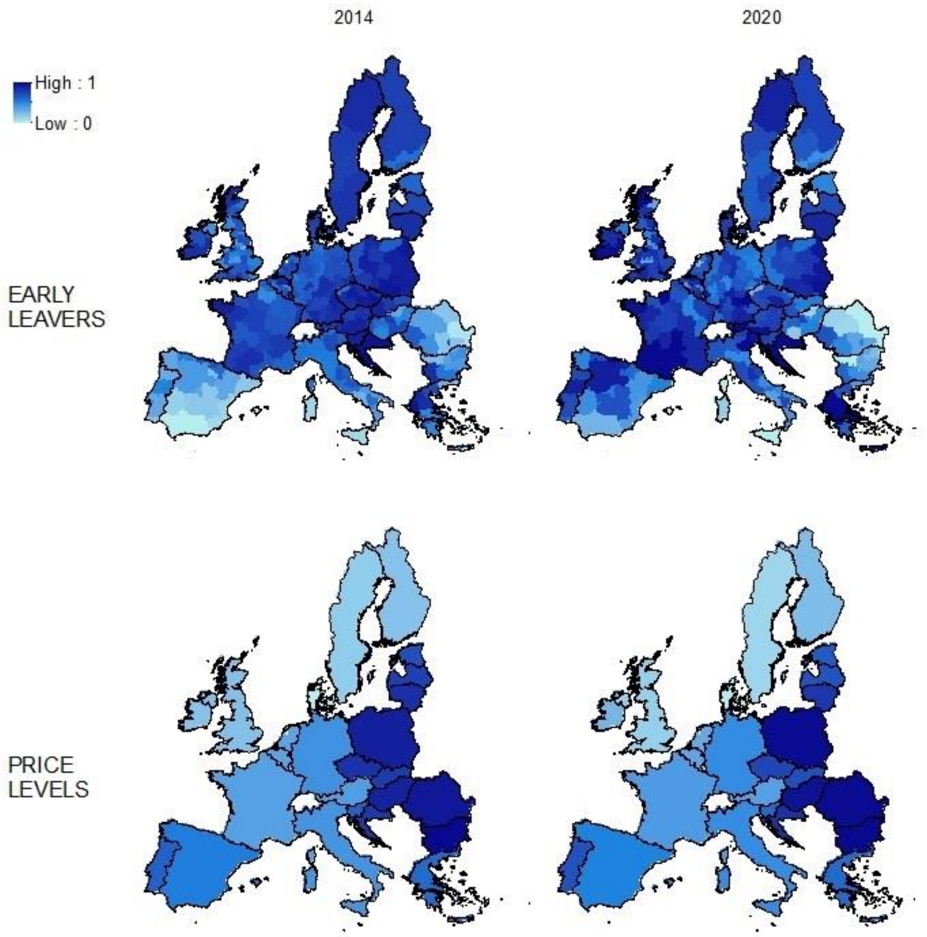

Figure 23. EU-28 fuzzy socioeconomic membership - part D.

Appendix E: Socioeconomic theme metadata

(retrieved from European Commission (2016))

1. Healthy Life Years at birth as a percentage of Life Expectancy: The indicator of healthy life years (HLY) measures the number of remaining years that a person of specific age is expected to live without any severe or moderate health problems. The notion of health problem for Eurostat's HLY is reflecting a disability dimension and is based on a self-perceived question which aims to measure the extent of any limitations, for at least six months, because of a health problem that may have affected respondents as regards activities they usually do (the so-called GALI - Global Activity Limitation Instrument foreseen in the annual EU-SILC survey). The indicator is therefor also called disability-free life expectancy (DFLE). So, HLY is a composite indicator that combines mortality data with health status data.
2. Real adjusted gross disposable income of households per capita: Real adjusted gross disposable income of households per capita in PPS is calculated as the adjusted gross disposable income of households and Non-Profit Institutions Serving Households (NPISH) divided by the purchasing power parities (PPP) of the actual individual consumption of households and by the total resident population.
3. Employment (total) ages, 20-64: Regional (NUTS level 2) employment rate of the age group 20-64 represents employed persons aged 20-64 as a percentage of the population of the same age group. The indicator is based on the EU Labour Force Survey. The survey covers the entire population living in private households and excludes those in collective households such as boarding houses, halls of residence and hospitals.
   The employed persons are those aged 20-64, who during the reference week did any work for pay, profit or family gain for at least one hour, or were not at work but had a job or business from which they were temporarily absent.
4. Severe material deprivation: The collection "material deprivation" covers indicators relating to economic strain, durables, housing and environment of the dwelling. Severely materially deprived persons have living conditions severely constrained by a lack of resources, they experience at least 4 out of 9 following deprivations items: they cannot afford
   i) to pay rent or utility bills,
   ii) keep home adequately warm,
   iii) face unexpected expenses,
   iv) eat meat, fish or a protein equivalent every second day,
   v) a week holiday away from home,
   vi) a car,
   vii) a washing machine,
   viii) a colour TV,
   ix) a telephone
5. Tertiary educational attainment (total), ages 30-34: The indicator is defined as the percentage of the population aged 30-34 who have successfully completed tertiary studies (e.g. university, higher technical institution, etc.). This educational attainment refers to ISCED (International Standard Classification of Education) 2011 level 5-8 for data from 2014 onwards and to ISCED 1997 level 5-6 for data up to 2013. The indicator is based on the EU Labour Force Survey.
6. Crimes recorded (aggregate): For 2008, 2009 and 2010 only, data on domestic burglary, homicide, robbery and theft of motor vehicle are available at a regional level.
7. Gender earnings gap: The gender overall earnings gap is a synthetic indicator. It measures the impact of the three combined factors, namely: (1) the average hourly earnings, (2) the monthly average of the number of hours paid (before any adjustment for part-time work) and (3) the employment rate, on the average earnings of all women of working age - whether employed or not employed - compared to men.
8. Gini coefficient of equivalised disposable income ("income gap": 0=perfect equality, 1=perfect inequality): The Gini coefficient is defined as the relationship of cumulative shares of the population arranged according to the level of equivalised disposable income, to the cumulative share of the equivalised total disposable income received by them.
9. People at risk of poverty or social exclusion: Persons who are at risk of poverty or severely materially deprived or living in households with very low work intensity. Persons are only counted once even if they are present in several sub-indicators. At risk-of-poverty are persons with an equivalised disposable income below the risk-of-poverty threshold, which is set at 60 % of the national median equivalised disposable income (after social transfers).
   Material deprivation covers indicators relating to economic strain and durables.
   Severely materially deprived persons have living conditions severely constrained by a lack of

resources, they experience at least 4 out of 9 following deprivations items: cannot afford
i) to pay rent or utility bills,
ii) keep home adequately warm,
iii) face unexpected expenses,
iv) eat meat, fish or a protein equivalent every second day,
v) a week holiday away from home, vi) a car, vii) a washing machine,
viii) a colour TV, or
ix) a telephone.
People living in households with very low work intensity are those aged 0-59 living in households where the adults (aged 18-59) work less than 20% of their total work potential during the past year.

10. Early leavers from education/training (total), ages 18-24: The indicator is defined as the percentage of the population aged 18-24 with at most lower secondary education and who were not in further education or training during the last four weeks preceding the survey. Lower secondary education refers to ISCED (International Standard Classification of Education) 2011 level 0-2 for data from 2014 onwards and to ISCED 1997 level 0-3C short for data up to 2013. The indicator is based on the EU Labour Force Survey.
11. Comparative price levels of final consumption by private households including indirect taxes: Comparative price levels are the ratio between Purchasing power parities (PPPs) and market exchange rate for each country. PPPs are currency conversion rates that convert economic indicators expressed in national currencies to a common currency, called Purchasing Power Standard (PPS), which equalises the purchasing power of different national currencies and thus allows meaningful comparison.
The ratio is shown in relation to the EU average (EU28 = 100). If the index of the comparative price levels shown for a country is higher/ lower than 100, the country concerned is relatively expensive/cheap as compared with the EU average.

Appendix F: Country statistics (NUTS 0)

Table 12. Observed year 2014, forecast year 2020, Goodness-of fit (R^2), and standard error (SE) of the simple linear regression.

NUTS ID	Healthy Life Years (%)				Disposable income (PPS)				Employment 20-64 (% of pop.)			
	2014	2020	R2	SE	2014	2020	R2	SE	2014	2020	R2	SE
AT	70.85	72.11	0.25	1.17	25,927	28,559	0.93	455.92	74.2	75.7	0.75	0.85
BE	78.90	81.30	0.19	1.53	23,778	26,574	0.99	174.78	67.3	70.3	0.84	0.96
BG	85.90	76.89	0.62	2.70	8,761	11,559	0.93	357.54	65.1	71.8	0.48	3.67
CY	80.00	79.90	0.05	1.89	16,813	18,145	0.00	1584.73	67.6	66.8	0.53	2.37
CZ	81.40	84.27	0.53	1.17	16,086	17,937	0.93	326.69	73.5	72.8	0.12	1.18
DE	69.65	70.45	0.05	1.52	27,159	31,041	0.96	468.52	77.7	80.2	0.88	1.43
DK	75.40	64.00	0.87	2.06	22,246	26,254	0.98	344.93	75.9	77.6	0.04	1.56
EE	71.60	74.06	0.05	1.97	13,074	16,179	0.89	568.02	74.3	75.8	0.26	3.03
EL	79.15	77.64	0.61	1.16	15,064	14,601	0.24	1453.26	53.3	58.8	0.05	3.95
ES	78.15	78.08	0.01	0.84	18,245	19,014	0.36	477.21	59.9	68.8	0.37	4.68
FI	71.65	76.65	0.35	2.45	23,153	27,575	0.97	460.59	73.1	76.9	0.53	1.84
FR	77.20	75.60	0.68	0.49	24,113	26,908	0.97	305.13	69.3	70.5	-	-
HR	76.25	74.56	0.08	2.65	12,417	14,282	0.95	238.09	59.2	59.5	0.03	2.52
HU	79.00	83.06	0.80	0.88	13,178	14,582	0.92	307.76	66.7	65.8	0.41	1.96
IE	82.30	84.87	0.72	0.68	19,403	20,245	0.15	760.40	67.0	71.3	0.14	4.44
IT	75.15	67.16	0.76	2.06	20,672	22,134	0.44	655.46	59.9	64.1	0.61	1.70
LT	80.15	84.60	0.47	1.66	15,432	18,663	0.97	400.49	71.8	71.6	0.17	2.52
LU	77.65	81.46	0.10	2.03	20,781	23,021	0.92	358.78	72.1	74.2	0.94	0.68
LV	72.05	73.32	0.02	1.69	11,979	13,779	0.57	1006.61	70.7	72.8	0.25	3.26
MT	89.40	89.53	0.28	0.81	20,781	23,021	0.92	358.78	66.4	66.9	0.73	1.77
NL	74.95	68.06	0.75	1.57	22,729	24,382	0.48	746.43	75.4	81.6	0.69	2.20
PL	79.00	75.81	0.43	1.53	14,254	18,050	0.99	220.41	66.5	67.8	0.38	2.79
PT	70.25	77.33	0.12	2.94	16,538	18,393	0.78	483.03	67.6	69.3	0.05	2.52
RO	78.75	70.39	0.65	1.95	12,376	16,006	0.92	779.57	65.7	62.5	0.26	2.00
SE	89.55	90.07	0.34	3.24	23,265	26,907	0.94	515.57	80.0	82.3	0.72	1.10
SI	72.40	65.62	0.34	3.25	16,360	17,867	0.73	498.66	67.7	69.7	0.00	1.75
SK	71.75	66.47	0.36	2.05	15,444	19,390	0.96	460.78	65.9	66.2	0.03	1.63
UK	78.40	76.97	0.81	0.57	22,509	22,053	0.11	794.66	76.2	77.0	0.62	1.07
EU28	76.25	73.64	0.93	0.20	20,781	23,021	0.92	358.78	69.2	70.6	0.48	0.85

NUTS ID	Severe mat. deprivation (% of pop.)				Tertiary educ. attainment (% of pop.)				Aggregate crimes recorded (No.)			
	2014	2020	R2	SE	2014	2020	R2	SE	2014	2020	R2	SE
AT	4.0	4.2	0.01	0.72	40.0	62.0	0.83	3.64	12,818	0	0.50	5112.09
BE	5.9	5.8	0.00	0.56	43.8	43.2	0.00	0.75	117,417	123,414	0.16	3228.02
BG	33.1	22.9	0.69	4.87	30.9	38.8	0.92	0.75	38,838	53,583	0.83	1550.12
CY	15.3	17.1	0.30	2.11	52.5	63.6	0.81	1.71	8,445	12,585	0.91	312.72
CZ	6.7	3.1	0.55	1.30	28.2	37.6	0.99	0.24	16,184	116	0.97	687.49
DE	5.0	5.3	0.06	0.36	31.4	33.9	0.29	0.85	265,371	282,555	0.98	569.10
DK	3.2	3.3	0.06	0.54	44.9	54.3	0.94	0.67	74,224	64,603	0.15	5488.90
EE	6.2	4.9	0.16	2.21	43.2	51.9	0.88	0.94	3,412	1,570	0.78	232.70
EL	21.5	25.5	0.65	2.75	37.2	54.6	0.99	0.41	170,452	256,513	0.96	3963.68

ES	7.1	7.7	0.64	0.73	42.3	40.9	0.10	0.65	218,815	156,385	0.90	4853.26
FI	2.8	1.8	0.80	0.24	45.3	44.5	0.42	0.32	14,457	7,296	1.00	20.00
FR	4.8	4.5	0.30	0.41	52.1	59.4	0.42	1.85	542,048	596,729	0.86	5292.94
HR	13.9	13.8	0.07	0.87	32.2	43.3	0.77	2.28	6,052	6,100	0.02	73.48
HU	24.0	25.7	0.15	2.93	34.1	43.3	0.95	0.71	35,788	42,322	0.54	1432.95
IE	8.4	12.5	0.77	1.03	52.2	56.0	0.70	0.76	28,996	15,121	0.49	3325.18
IT	11.6	16.7	0.68	1.67	23.9	31.1	0.99	0.26	350,701	258,256	0.75	12454.43
LT	13.6	7.3	0.40	4.81	53.3	71.3	0.99	0.61	5,035	0	0.99	191.06
LU	1.4	1.6	0.09	0.43	52.7	59.0	0.77	1.13	1,930	1,411	0.18	264.14
LV	19.2	12.6	0.42	5.31	39.9	48.5	0.83	1.10	6,132	5,031	0.14	653.61
MT	10.2	12.6	0.75	1.20	26.5	33.0	0.98	0.29	1,383	1,533	0.76	19.60
NL	3.2	3.0	0.25	0.48	44.8	52.5	0.99	0.26	153,868	190,072	0.95	1912.23
PL	10.4	0.0	0.83	3.31	42.1	52.1	0.98	0.43	81,048	91,788	0.88	947.95
PT	10.6	9.9	0.04	0.77	31.3	39.3	0.97	0.47	49,898	24,791	0.89	2057.98
RO	25.0	16.9	0.84	1.91	25.0	32.8	0.98	0.36	27,661	39,787	1.00	94.71
SE	0.7	0.0	0.86	0.27	49.9	54.8	0.96	0.33	49,354	25,996	0.88	2040.42
SI	6.6	7.3	0.43	0.52	41.0	49.3	0.96	0.49	4,682	6,341	1.00	14.29
SK	9.9	2.4	0.71	2.28	26.9	35.3	0.91	0.79	4,231	598	0.85	358.03
UK	7.4	8.9	0.46	1.26	47.7	51.0	0.85	0.43	326,740	103,054	0.94	13435.45
EU28	8.9	8.6	0.01	0.77	37.9	43.7	0.99	0.17	-	-	-	-

NUTS ID	**Gender overall earnings gap (%)**				**GINI coeff. of equiv. disp. income (0-100)**				**Risk of poverty/soc. exclusion (% of pop.)**			
	2014	**2020**	**R2**	**SE**	**2014**	**2020**	**R2**	**SE**	**2014**	**2020**	**R2**	**SE**
AT	44.5	38.1	0.95	0.98	27.6	28.7	0.42	0.72	19.2	19.7	0.16	0.98
BE	31.2	24.0	0.98	0.78	25.9	25.4	0.34	0.62	21.2	20.4	0.21	0.57
BG	22.8	18.5	0.89	1.03	35.4	37.6	0.33	1.45	40.1	31.8	0.60	4.77
CY	26.6	10.1	0.99	1.10	34.8	36.1	0.75	1.09	27.4	28.6	0.35	1.34
CZ	40.5	39.1	0.68	0.85	25.1	24.4	0.36	0.32	14.8	11.7	0.55	1.22
DE	45.3	42.3	0.81	0.90	30.7	31.8	0.37	1.24	20.6	20.9	0.18	0.61
DK	27.2	22.9	0.59	2.08	27.7	29.8	0.84	0.61	17.9	18.8	0.53	0.48
EE	38.9	36.4	0.01	4.94	35.6	32.6	0.01	2.01	26.0	23.5	0.00	1.76
EL	39.1	26.7	1.00	0.00	34.5	34.7	0.27	0.56	36.0	38.4	0.54	2.39
ES	35.8	20.3	0.95	2.42	34.7	36.4	0.92	0.36	29.2	30.9	0.77	0.98
FI	24.5	18.7	1.00	0.08	25.6	25.2	0.27	0.31	17.3	16.7	0.09	0.45
FR	31.1	31.1	-	-	29.2	31.5	0.39	1.10	18.5	18.1	0.23	0.44
HR	23.0	23.0	-	-	30.2	29.2	0.79	0.25	29.3	26.1	0.43	1.32
HU	32.4	28.7	0.83	1.12	28.6	27.1	0.00	2.67	31.8	31.9	0.02	2.19
IE	37.5	25.5	0.76	4.28	30.8	28.7	0.34	0.85	27.6	33.1	0.64	1.64
IT	43.5	39.2	0.92	0.82	32.4	32.3	0.00	0.52	28.3	30.5	0.46	1.30
LT	20.0	10.8	0.37	6.37	35	35.2	0.00	1.82	27.3	25.1	0.31	3.53
LU	32.3	22.0	0.99	0.65	28.7	30.2	0.47	0.85	19.0	20.3	0.57	0.84
LV	23.1	15.6	0.19	6.90	35.5	34.0	0.36	1.04	32.7	27.3	0.55	3.14
MT	46.8	31.8	0.97	2.08	27.7	28.5	0.24	0.60	23.8	26.8	0.84	0.72
NL	48.3	43.9	0.85	1.44	26.2	24.9	0.33	0.76	16.5	16.1	0.03	0.72
PL	31.7	31.4	0.00	2.17	30.8	28.0	0.71	0.85	24.7	10.0	0.81	3.15
PT	26.5	27.0	0.00	1.35	34.5	31.3	0.81	0.75	27.5	26.6	0.04	1.15
RO	26.9	24.2	0.20	3.91	34.7	34.2	0.03	1.79	39.5	34.0	0.77	1.44
SE	27.1	28.2	0.04	3.24	25.4	26.3	0.85	0.31	16.9	16.6	0.11	0.95

SI	19.7	11.6	0.37	4.80	25	25.1	0.44	0.50	20.4	21.5	0.58	0.84
SK	37.5	33.4	0.60	2.60	26.1	23.7	0.16	1.26	18.4	11.0	0.59	2.80
UK	45.7	40.1	1.00	0.19	31.6	30.1	0.44	0.94	24.1	23.9	0.02	0.93
EU28	39.8	34.9	0.97	0.61	30.9	31.3	0.39	0.22	24.4	24.3	0.00	0.49

NUTS ID	**Early leavers 18-24 (% of pop.)**				**Comp. price levels priv. househ. (EU28=100)**			
	2014	**2020**	**R2**	**SE**	**2014**	**2020**	**R2**	**SE**
AT	7	5.4	0.78	0.31	105.8	108.0	0.42	1.39
BE	9.8	6.4	0.88	0.44	108.7	110.6	0.10	1.80
BG	12.9	15.1	0.93	0.18	47.9	53.0	0.38	2.51
CY	6.8	0.0	0.94	0.78	90.1	90.8	0.01	2.22
CZ	5.5	7.3	0.79	0.25	63.7	75.1	0.16	6.86
DE	9.5	7.5	0.60	0.59	101.5	99.7	0.32	1.63
DK	7.8	5.0	0.86	0.36	139.1	138.3	0.06	1.75
EE	11.4	12.3	0.28	0.67	75.6	83.2	0.54	3.38
EL	9	1.6	0.99	0.19	85.4	88.0	0.04	3.87
ES	21.9	12.5	0.99	0.25	92.3	95.1	0.03	2.65
FI	9.5	8.9	0.08	0.37	122.3	120.3	0.17	1.47
FR	9	4.1	0.86	0.67	107.7	106.7	0.20	1.66
HR	2.7	0.0	0.83	0.57	66.1	67.4	0.09	3.71
HU	11.4	11.6	0.00	0.26	57.5	56.1	0.36	2.94
IE	6.9	1.1	0.95	0.45	122.3	117.8	0.28	3.04
IT	15	10.4	0.93	0.42	102.9	100.6	0.43	1.09
LT	5.9	3.2	0.95	0.19	62.8	69.9	0.44	3.38
LU	6.1	10.1	0.20	1.51	120.4	129.5	0.60	3.72
LV	8.5	6.2	0.58	0.85	70.1	80.5	0.42	5.27
MT	20.3	16.3	0.87	0.47	80.9	85.7	0.92	0.87
NL	8.7	7.3	0.63	0.31	109.8	112.8	0.63	1.64
PL	5.4	4.9	0.75	0.09	55.8	54.1	0.15	4.22
PT	17.4	3.5	0.97	0.68	81.8	79.5	0.49	2.03
RO	18.1	19.7	0.31	0.63	53.1	54.2	0.01	5.65
SE	6.7	7.0	0.00	0.41	125.6	130.0	0.24	6.10
SI	4.4	5.5	0.40	0.36	81.7	88.1	0.29	3.64
SK	6.7	9.6	0.92	0.28	67.8	78.6	0.48	4.77
UK	11.8	5.8	0.98	0.28	121.5	127.7	0.37	7.31
EU28	11.2	7.6	0.97	0.20	100.0	100.0	-	0.00

Appendix G: Observation point NUTS level frequencies by country and theme

Table 13. Observation point NUTS level frequencies by country and theme.

NUTS LEVEL	COUNTRY CODE	HEALTH	DISP. INCOME	EMPLOYMENT	MAT. DEPRIV	EDUCATION	CRIME	GENDER GAP	INCOME GAP	POVERTY RISK	EARLY LEAVERS	PRICE LEVELS	TOTAL POINTS
0	AT	293	293	-	-	-	-	293	293	293	-	293	**1758**
0	BE	109	109	-	-	-	-	109	109	109	-	109	**654**
0	BG	397	397	-	-	-	-	397	397	-	-	397	**1985**
0	CZ	265	265	-	-	-	-	265	265	-	-	265	**1325**
0	DE	1222	1222	-	1222	-	-	1222	1222	1222	-	1222	**8554**
0	DK	179	179	-	-	-	-	179	179	-	-	179	**895**
0	EE	171	171	-	171	-	171	171	171	171	-	171	**1368**
0	EL	527	527	-	-	-	527	527	527	-	-	527	**3162**
0	ES	1727	1727	-	-	-	-	1727	1727	-	-	1727	**8635**
0	FI	1199	1199	-	-	-	-	1199	1199	-	-	1199	**5995**
0	FR	1898	1898	-	1898	-	-	1898	1898	1898	-	1898	**13286**
0	HR	237	237	-	237	-	-	237	237	237	-	237	**1659**
0	HU	322	322	-	-	-	-	322	322	-	-	322	**1610**
0	IE	255	255	-	-	-	255	255	255	-	-	255	**1530**
0	IT	1101	1101	-	-	-	427	1101	1101	-	-	1101	**5932**
0	LT	235	235	-	235	-	-	235	235	235	-	235	**1645**
0	LU	9	9	-	9	-	-	9	9	9	-	9	**63**
0	LV	234	234	-	234	-	-	234	234	234	-	234	**1638**
0	MT	2	2	-	2	-	-	2	2	2	-	2	**14**
0	NL	134	134	-	-	-	-	134	134	-	-	134	**670**
0	PL	1089	1089	-	-	-	-	1089	1089	-	-	1089	**5445**
0	PT	310	310	-	310	-	-	310	310	310	-	310	**2170**
0	RO	846	846	-	-	-	-	846	846	-	-	846	**4230**
0	SE	1583	1583	-	-	-	-	1583	1583	-	-	1583	**7915**
0	SI	64	64	-	64	-	64	64	64	64	-	64	**512**
0	SK	167	167	-	-	-	-	167	167	-	-	167	**835**
0	UK	898	898	-	898	-	541	898	898	898	-	898	**6827**

NUTS LEVEL	COUNTRY CODE	HEALTH	DISP. INCOME	EMPLOYMENT	MAT. DEPRIV	EDUCATION	CRIME	GENDER GAP	INCOME GAP	POVERTY RISK	EARLY LEAVERS	PRICE LEVELS	TOTAL POINTS
1	AT	-	-	-	-	-	-	-	-	-	-	-	**0**
1	BE	-	-	-	109	-	-	-	-	-	-	-	**109**
1	BG	-	-	-	-	-	-	-	-	-	-	-	**0**
1	CZ	-	-	-	-	-	-	-	-	-	-	-	**0**
1	DE	-	-	-	-	-	81	-	-	-	-	-	**81**
1	DK	-	-	-	-	-	-	-	-	-	-	-	**0**
1	EE	-	-	-	-	-	-	-	-	-	-	-	**0**
1	EL	-	-	-	527	-	-	-	-	527	-	-	**1054**
1	ES	-	-	-	-	-	-	-	-	-	-	-	**0**
1	FI	-	-	-	-	-	-	-	-	6	-	-	**6**
1	FR	-	-	-	-	-	-	-	-	-	-	-	**0**
1	HR	-	-	-	-	-	-	-	-	-	-	-	**0**
1	HU	-	-	-	322	-	-	-	-	322	-	-	**644**
1	IE	-	-	-	-	-	-	-	-	-	-	-	**0**
1	IT	-	-	-	-	-	-	-	-	-	-	-	**0**
1	LT	-	-	-	-	-	-	-	-	-	-	-	**0**
1	LU	-	-	-	-	-	-	-	-	-	-	-	**0**
1	LV	-	-	-	-	-	-	-	-	-	-	-	**0**
1	MT	-	-	-	-	-	-	-	-	-	-	-	**0**
1	NL	-	-	-	134	-	-	-	-	134	-	-	**268**
1	PL	-	-	-	1089	-	-	-	-	1089	-	-	**2178**
1	PT	-	-	-	-	-	-	-	-	-	-	-	**0**
1	RO	-	-	-	-	-	-	-	-	-	-	-	**0**
1	SE	-	-	-	-	-	-	-	-	-	-	-	**0**
1	SI	-	-	-	-	-	-	-	-	-	-	-	**0**
1	SK	-	-	-	-	-	-	-	-	-	-	-	**0**
1	UK	-	-	-	-	-	305	-	-	-	-	-	**305**

NUTS LEVEL	COUNTRY CODE	HEALTH	DISP. INCOME	EMPLOYMENT	MAT. DEPRIV	EDUCATION	CRIME	GENDER GAP	INCOME GAP	POVERTY RISK	EARLY LEAVERS	PRICE LEVELS	TOTAL POINTS
2	AT	-	-	293	293	293	292	-	-	-	293	-	**1464**
2	BE	-	-	109	-	109	-	-	-	-	109	-	**327**
2	BG	-	-	397	397	397	-	-	-	397	397	-	**1985**
2	CZ	-	-	265	265	265	-	-	-	265	265	-	**1325**
2	DE	-	-	1222	-	1222	-	-	-	-	1222	-	**3666**
2	DK	-	-	179	179	179	-	-	-	179	179	-	**895**
2	EE	-	-	171	-	171	-	-	-	-	171	-	**513**
2	EL	-	-	527	-	527	-	-	-	-	527	-	**1581**
2	ES	-	-	1727	1727	1727	-	-	-	1727	1727	-	**8635**
2	FI	-	-	1199	1199	1199	-	-	-	1193	1199	-	**5989**
2	FR	-	-	1898	-	1898	-	-	-	-	1898	-	**5694**
2	HR	-	-	237	-	237	-	-	-	-	237	-	**711**
2	HU	-	-	322	-	322	-	-	-	-	322	-	**966**
2	IE	-	-	255	255	255	-	-	-	255	255	-	**1275**
2	IT	-	-	1101	1101	1101	674	-	-	1101	1101	-	**6179**
2	LT	-	-	235	-	235	-	-	-	-	235	-	**705**
2	LU	-	-	9	-	9	-	-	-	-	9	-	**27**
2	LV	-	-	234	-	234	-	-	-	-	234	-	**702**
2	MT	-	-	2	-	2	-	-	-	-	2	-	**6**
2	NL	-	-	134	-	134	-	-	-	-	134	-	**402**
2	PL	-	-	1089	-	1089	302	-	-	-	1089	-	**3569**
2	PT	-	-	310	-	310	207	-	-	-	310	-	**1137**
2	RO	-	-	846	846	846	-	-	-	846	846	-	**4230**
2	SE	-	-	1583	1583	1583	-	-	-	1583	1583	-	**7915**
2	SI	-	-	64	-	64	-	-	-	-	64	-	**192**
2	SK	-	-	167	167	167	-	-	-	167	167	-	**835**
2	UK	-	-	898	-	898	-	-	-	-	898	-	**2694**

NUTS LEVEL	COUNTRY CODE	HEALTH	DISP. INCOME	EMPLOYMENT	MAT. DEPRIV	EDUCATION	CRIME	GENDER GAP	INCOME GAP	POVERTY RISK	EARLY LEAVERS	PRICE LEVELS	TOTAL POINTS
3	AT	-	-	-	-	-	1	-	-	-	-	-	**1**
3	BE	-	-	-	-	-	109	-	-	-	-	-	**109**
3	BG	-	-	-	-	-	397	-	-	-	-	-	**397**
3	CZ	-	-	-	-	-	265	-	-	-	-	-	**265**
3	DE	-	-	-	-	-	1141	-	-	-	-	-	**1141**
3	DK	-	-	-	-	-	179	-	-	-	-	-	**179**
3	EE	-	-	-	-	-	-	-	-	-	-	-	**0**
3	EL	-	-	-	-	-	-	-	-	-	-	-	**0**
3	ES	-	-	-	-	-	1727	-	-	-	-	-	**1727**
3	FI	-	-	-	-	-	1199	-	-	-	-	-	**1199**
3	FR	-	-	-	-	-	1898	-	-	-	-	-	**1898**
3	HR	-	-	-	-	-	237	-	-	-	-	-	**237**
3	HU	-	-	-	-	-	322	-	-	-	-	-	**322**
3	IE	-	-	-	-	-	-	-	-	-	-	-	**0**
3	IT	-	-	-	-	-	-	-	-	-	-	-	**0**
3	LT	-	-	-	-	-	235	-	-	-	-	-	**235**
3	LU	-	-	-	-	-	9	-	-	-	-	-	**9**
3	LV	-	-	-	-	-	234	-	-	-	-	-	**234**
3	MT	-	-	-	-	-	2	-	-	-	-	-	**2**
3	NL	-	-	-	-	-	134	-	-	-	-	-	**134**
3	PL	-	-	-	-	-	787	-	-	-	-	-	**787**
3	PT	-	-	-	-	-	103	-	-	-	-	-	**103**
3	RO	-	-	-	-	-	846	-	-	-	-	-	**846**
3	SE	-	-	-	-	-	1583	-	-	-	-	-	**1583**
3	SI	-	-	-	-	-	-	-	-	-	-	-	**0**
3	SK	-	-	-	-	-	167	-	-	-	-	-	**167**
3	UK	-	-	-	-	-	52	-	-	-	-	-	**52**
	TOTAL POINTS	15473	15473	15473	15473	15473	15473	15473	15473	15473	15473	15473	170203

Appendix H: Exploratory Regression and OLS regression

Exploratory Regression analysis of all possible model combinations and Ordinary Least Squares (OLS) regression analysis (ArcGIS Spatial Statistics) utilizing the 12 MCE factors (explanatory variables) against 2013 EU-SILC country-level survey results (dependent variable); for this analysis, the factors have not been normalized and no fuzzy memberships have been calculated, i.e. they are "raw." 15,473 observation points were used.

Table 14. 12 factor model Exploratory Regression result. The strength of positive and/or negative factor impact on the dependent variable (2013 EU-SILC) is indicated.

Exploratory Regression:
Summary of Variable Significance

Variable	% Significant	% Negative	% Positive
INC_EQ	100.00	100.00	0.00
MTRL	100.00	100.00	0.00
TCI_STD	100.00	100.00	0.00
PR_LVLS	97.12	3.12	96.88
GENDER	96.88	89.21	10.79
DISP_INC	96.78	2.44	97.56
POV	95.95	32.18	67.82
LEAVERS	93.90	33.64	66.36
EDUC	93.36	28.03	71.97
EMPL	92.92	23.44	76.56
CRIME	88.77	86.87	13.13
HEALTH	87.99	45.41	54.59

Table 15. 12 factor model OLS regression analysis result. The coefficients indicate the impact a change of 1 factor unit has on the dependent variable (2013 EU-SILC), and the statistical significance of each factor to explain the dependent variable. All factors except Price Levels are found to be significant, with very low Robust Probability values. Interestingly, climatic comfort (standard scale TCI) appears to have a negative impact on well-being levels. The model achieved an Adjusted R^2 value (i.e. the "explanatory power" of the model) of 0.78 and a low level of factor redundancy (VIF). The Joint Wald Statistic indicates the model is statistically significant, but with variation in geographic (nonstationarity) and/or data (heteroscedasticity) space (Koenker Statistic).

Variable	Coefficient [a]	StdError	t_Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	8.840492	0.070520	125.360974	0.000000	0.066537	132.866755	0.000000*	--------
CRIME	0.002359	0.000892	2.645060	0.008171	0.000738	3.198383	0.001401*	1.075603
DISP_INC	0.000007	0.000001	5.236654	0.000000	0.000001	5.923799	0.000000*	7.247507
LEAVERS	0.009170	0.000677	13.546973	0.000000	0.000804	11.412419	0.000000*	2.680895
EDUC	0.001576	0.000359	4.385189	0.000015	0.000339	4.648309	0.000005*	2.186156
EMPL	0.011761	0.000511	23.017108	0.000000	0.000520	22.600343	0.000000*	3.218991
GENDER	-0.004437	0.000419	-10.592177	0.000000	0.000405	-10.943465	0.000000*	1.724988
HEALTH	-0.005180	0.000569	-9.108879	0.000000	0.000518	-9.998563	0.000000*	1.561742
INC_EQ	-0.084778	0.001345	-63.051494	0.000000	0.001406	-60.312803	0.000000*	3.574311
MTRL	-0.059607	0.000737	-80.891443	0.000000	0.001054	-56.545851	0.000000*	6.296943
POV	0.044730	0.000694	64.437103	0.000000	0.000757	59.103836	0.000000*	6.457637
PR_LVLS	0.000315	0.000227	1.390472	0.164419	0.000197	1.603182	0.108929	5.353075
TCI_STD	-0.008618	0.000188	-45.759694	0.000000	0.000209	-41.289690	0.000000*	2.141624

Input Features:	MERGED_2014_RAW	Dependent Variable:	EUSILC
Number of Observations:	15473	Akaike's Information Criterion (AICc) [d]:	7227.667493
Multiple R-Squared [d]:	0.7771	Adjusted R-Squared [d]:	0.776927
Joint F-Statistic [e]:	4491.527345	Prob(>F), (12,15460) degrees of freedom:	0.000000*
Joint Wald Statistic [e]:	66477.46858	Prob(>chi-squared), (12) degrees of freedom:	0.000000*
Koenker (BP) Statistic [f]:	8766.024976	Prob(>chi-squared), (12) degrees of freedom:	0.000000*
Jarque-Bera Statistic [g]:	1961.747037	Prob(>chi-squared), (2) degrees of freedom:	0.000000*

Notes on Interpretation

* An asterisk next to a number indicates a statistically significant p-value (p < 0.01).

[a] Coefficient: Represents the strength and type of relationship between each explanatory variable and the dependent variable.

[b] Probability and Robust Probability (Robust_Pr): Asterisk (*) indicates a coefficient is statistically significant (p < 0.01); if the Koenker (BP) Statistic [f] is statistically significant, use the Robust Probability column (Robust_Pr) to determine coefficient significance.

[c] Variance Inflation Factor (VIF): Large Variance Inflation Factor (VIF) values (> 7.5) indicate redundancy among explanatory variables.

[d] R-Squared and Akaike's Information Criterion (AICc): Measures of model fit/performance.

[e] Joint F and Wald Statistics: Asterisk (*) indicates overall model significance (p < 0.01); if the Koenker (BP) Statistic [f] is statistically significant, use the Wald Statistic to determine overall model significance.

[f] Koenker (BP) Statistic: When this test is statistically significant (p < 0.01), the relationships modeled are not consistent (either due to non-stationarity or heteroscedasticity). You should rely on the Robust Probabilities (Robust_Pr) to determine coefficient significance and on the Wald Statistic to determine overall model significance.

[g] Jarque-Bera Statistic: When this test is statistically significant (p < 0.01) model predictions are biased (the residuals are not normally distributed).

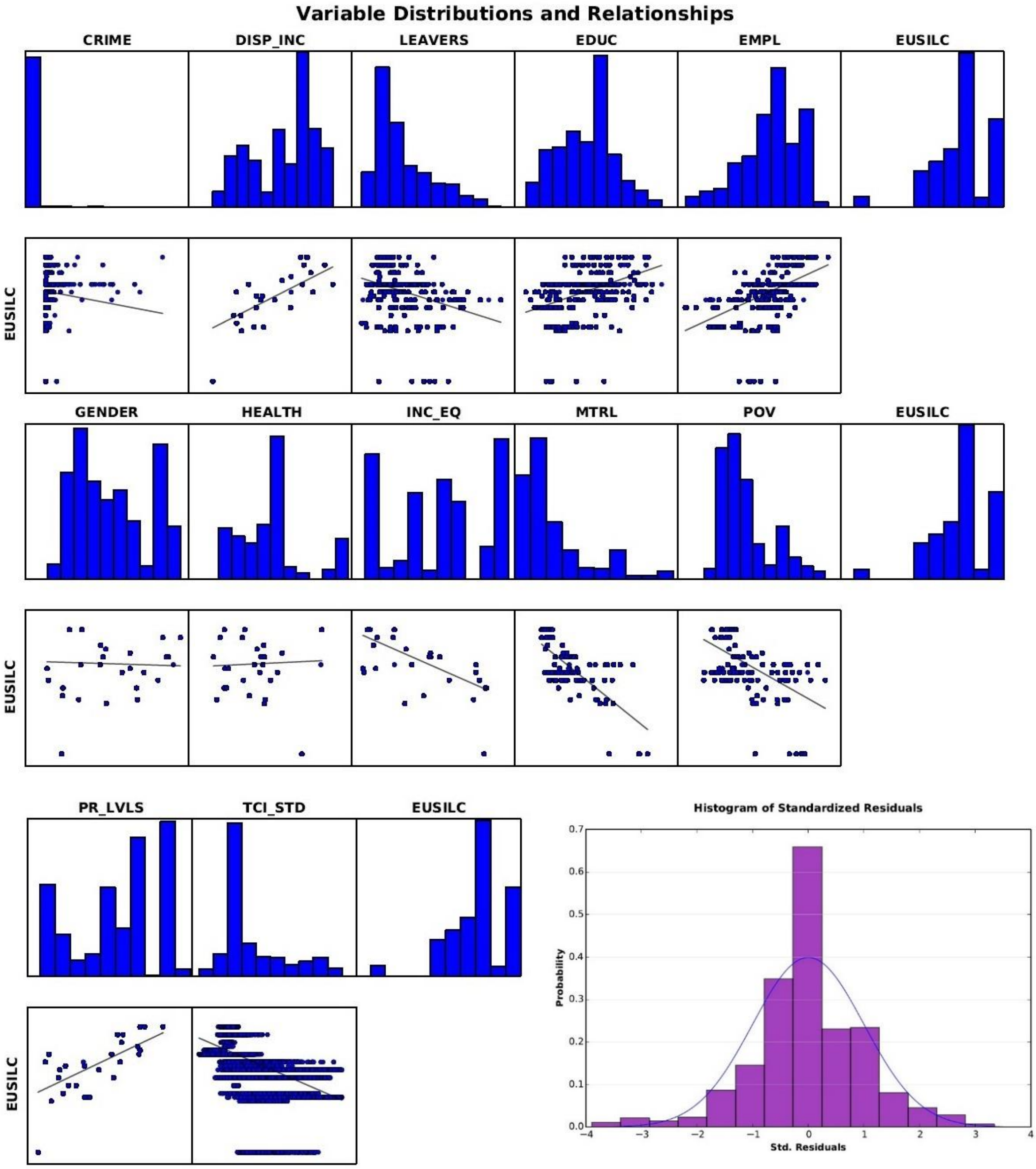

Figure 24. Variable distributions and scatter plots of the explanatory variables and the dependent variable. Trend line slopes indicate the strength and direction of each variable. The standardized regression residuals exhibit a near normal distribution, indicating some model bias/model misspecification with some explanatory variables missing (which would be expected as per the discussion of Section 2.1).

Spatial distribution of standardized OLS residuals

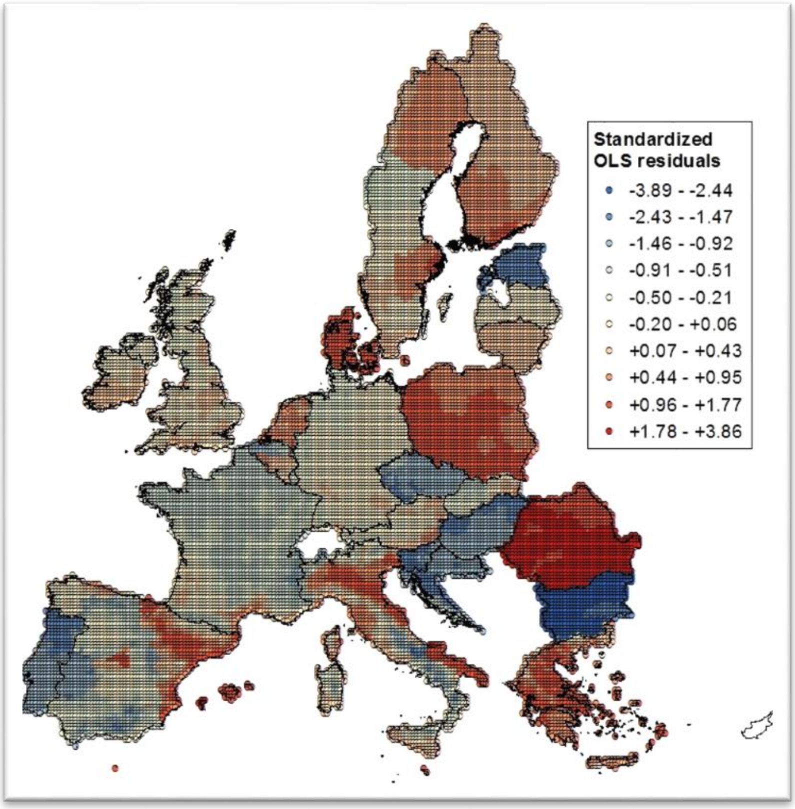

Figure 25. Spatial distribution of the standardized OLS residuals (standard deviations). Residual = observed – predicted. BLUE indicates model overestimation, RED indicates model underestimation.

Series from Lund University

Department of Physical Geography and Ecosystem Science

Master Thesis in Geographical Information Science

1. *Anthony Lawther:* The application of GIS-based binary logistic regression for slope failure susceptibility mapping in the Western Grampian Mountains, Scotland (2008).
2. *Rickard Hansen:* Daily mobility in Grenoble Metropolitan Region, France. Applied GIS methods in time geographical research (2008).
3. *Emil Bayramov:* Environmental monitoring of bio-restoration activities using GIS and Remote Sensing (2009).
4. *Rafael Villarreal Pacheco:* Applications of Geographic Information Systems as an analytical and visualization tool for mass real estate valuation: a case study of Fontibon District, Bogota, Columbia (2009).
5. *Siri Oestreich Waage:* a case study of route solving for oversized transport: The use of GIS functionalities in transport of transformers, as part of maintaining a reliable power infrastructure (2010).
6. *Edgar Pimiento:* Shallow landslide susceptibility – Modelling and validation (2010).
7. *Martina Schäfer:* Near real-time mapping of floodwater mosquito breeding sites using aerial photographs (2010).
8. *August Pieter van Waarden-Nagel:* Land use evaluation to assess the outcome of the programme of rehabilitation measures for the river Rhine in the Netherlands (2010).
9. *Samira Muhammad:* Development and implementation of air quality data mart for Ontario, Canada: A case study of air quality in Ontario using OLAP tool. (2010).
10. *Fredros Oketch Okumu*: Using remotely sensed data to explore spatial and temporal relationships between photosynthetic productivity of vegetation and malaria transmission intensities in selected parts of Africa (2011).
11. *Svajunas Plunge:* Advanced decision support methods for solving diffuse water pollution problems (2011).
12. *Jonathan Higgins:* Monitoring urban growth in greater Lagos: A case study using GIS to monitor the urban growth of Lagos 1990 - 2008 and produce future growth prospects for the city (2011).
13. *Mårten Karlberg:* Mobile Map Client API: Design and Implementation for Android (2011).
14. *Jeanette McBride:* Mapping Chicago area urban tree canopy using color infrared imagery (2011).
15. *Andrew Farina:* Exploring the relationship between land surface temperature and vegetation abundance for urban heat island mitigation in Seville, Spain (2011).
16. *David Kanyari*: Nairobi City Journey Planner: An online and a Mobile Application (2011).
17. *Laura V. Drews:* Multi-criteria GIS analysis for siting of small wind power plants - A case study from Berlin (2012).
18. *Qaisar Nadeem:* Best living neighborhood in the city - A GIS based multi criteria evaluation of ArRiyadh City (2012).

19. *Ahmed Mohamed El Saeid Mustafa:* Development of a photo voltaic building rooftop integration analysis tool for GIS for Dokki District, Cairo, Egypt (2012).
20. *Daniel Patrick Taylor*: Eastern Oyster Aquaculture: Estuarine Remediation via Site Suitability and Spatially Explicit Carrying Capacity Modeling in Virginia's Chesapeake Bay (2013).
21. *Angeleta Oveta Wilson:* A Participatory GIS approach to *unearthing* Manchester's Cultural Heritage '*gold mine'* (2013).
22. *Ola Svensson:* Visibility and Tholos Tombs in the Messenian Landscape: A Comparative Case Study of the Pylian Hinterlands and the Soulima Valley (2013).
23. *Monika Ogden:* Land use impact on water quality in two river systems in South Africa (2013).
24. *Stefan Rova:* A GIS based approach assessing phosphorus load impact on Lake Flaten in Salem, Sweden (2013).
25. *Yann Buhot:* Analysis of the history of landscape changes over a period of 200 years. How can we predict past landscape pattern scenario and the impact on habitat diversity? (2013).
26. *Christina Fotiou:* Evaluating habitat suitability and spectral heterogeneity models to predict weed species presence (2014).
27. *Inese Linuza:* Accuracy Assessment in Glacier Change Analysis (2014).
28. *Agnieszka Griffin:* Domestic energy consumption and social living standards: a GIS analysis within the Greater London Authority area (2014).
29. *Brynja Guðmundsdóttir:* Detection of potential arable land with remote sensing and GIS - A Case Study for Kjósarhreppur (2014).
30. *Oleksandr Nekrasov:* Processing of MODIS Vegetation Indices for analysis of agricultural droughts in the southern Ukraine between the years 2000-2012 (2014).
31. *Sarah Tressel:* Recommendations for a polar Earth science portal in the context of Arctic Spatial Data Infrastructure (2014).
32. *Caroline Gevaert:* Combining Hyperspectral UAV and Multispectral Formosat-2 Imagery for Precision Agriculture Applications (2014).
33. *Salem Jamal-Uddeen:* Using GeoTools to implement the multi-criteria evaluation analysis - weighted linear combination model (2014).
34. *Samanah Seyedi-Shandiz:* Schematic representation of geographical railway network at the Swedish Transport Administration (2014).
35. *Kazi Masel Ullah:* Urban Land-use planning using Geographical Information System and analytical hierarchy process: case study Dhaka City (2014).
36. *Alexia Chang-Wailing Spitteler:* Development of a web application based on MCDA and GIS for the decision support of river and floodplain rehabilitation projects (2014).
37. *Alessandro De Martino:* Geographic accessibility analysis and evaluation of potential changes to the public transportation system in the City of Milan (2014).
38. *Alireza Mollasalehi:* GIS Based Modelling for Fuel Reduction Using Controlled Burn in Australia. Case Study: Logan City, QLD (2015).
39. *Negin A. Sanati:* Chronic Kidney Disease Mortality in Costa Rica; Geographical Distribution, Spatial Analysis and Non-traditional Risk Factors (2015).

40. *Karen McIntyre:* Benthic mapping of the Bluefields Bay fish sanctuary, Jamaica (2015).
41. *Kees van Duijvendijk:* Feasibility of a low-cost weather sensor network for agricultural purposes: A preliminary assessment (2015).
42. *Sebastian Andersson Hylander:* Evaluation of cultural ecosystem services using GIS (2015).
43. *Deborah Bowyer:* Measuring Urban Growth, Urban Form and Accessibility as Indicators of Urban Sprawl in Hamilton, New Zealand (2015).
44. *Stefan Arvidsson:* Relationship between tree species composition and phenology extracted from satellite data in Swedish forests (2015).
45. *Damián Giménez Cruz*: GIS-based optimal localisation of beekeeping in rural Kenya (2016).
46. *Alejandra Narváez Vallejo:* Can the introduction of the topographic indices in LPJ-GUESS improve the spatial representation of environmental variables? (2016).
47. *Anna Lundgren:* Development of a method for mapping the highest coastline in Sweden using breaklines extracted from high resolution digital elevation models (2016).
48. *Oluwatomi Esther Adejoro:* Does location also matter? A spatial analysis of social achievements of young South Australians (2016).
49. *Hristo Dobrev Tomov:* Automated temporal NDVI analysis over the Middle East for the period 1982 - 2010 (2016).
50. *Vincent Muller:* Impact of Security Context on Mobile Clinic Activities A GIS Multi Criteria Evaluation based on an MSF Humanitarian Mission in Cameroon (2016).
51. *Gezahagn Negash Seboka:* Spatial Assessment of NDVI as an Indicator of Desertification in Ethiopia using Remote Sensing and GIS (2016).
52. *Holly Buhler:* Evaluation of Interfacility Medical Transport Journey Times in Southeastern British Columbia. (2016).
53. *Lars Ole Grottenberg*: Assessing the ability to share spatial data between emergency management organisations in the High North (2016).
54. *Sean Grant:* The Right Tree in the Right Place: Using GIS to Maximize the Net Benefits from Urban Forests (2016).
55. *Irshad Jamal:* Multi-Criteria GIS Analysis for School Site Selection in Gorno-Badakhshan Autonomous Oblast, Tajikistan (2016).
56. *Fulgencio Sanmartín:* Wisdom-volkano: A novel tool based on open GIS and time-series visualization to analyse and share volcanic data (2016).
57. *Nezha Acil:* Remote sensing-based monitoring of snow cover dynamics and its influence on vegetation growth in the Middle Atlas Mountains (2016).
58. *Julia Hjalmarsson:* A Weighty Issue: Estimation of Fire Size with Geographically Weighted Logistic Regression (2016).
59. *Mathewos Tamiru Amato:* Using multi-criteria evaluation and GIS for chronic food and nutrition insecurity indicators analysis in Ethiopia (2016).
60. *Karim Alaa El Din Mohamed Soliman El Attar:* Bicycling Suitability in Downtown, Cairo, Egypt (2016).
61. *Gilbert Akol Echelai:* Asset Management: Integrating GIS as a Decision Support Tool in Meter Management in National Water and Sewerage Corporation (2016).
62. *Terje Slinning:* Analytic comparison of multibeam echo soundings (2016).

63. *Gréta Hlín Sveinsdóttir:* GIS-based MCDA for decision support: A framework for wind farm siting in Iceland (2017).
64. *Jonas Sjögren:* Consequences of a flood in Kristianstad, Sweden: A GIS-based analysis of impacts on important societal functions (2017).
65. *Nadine Raska:* 3D geologic subsurface modelling within the Mackenzie Plain, Northwest Territories, Canada (2017).
66. *Panagiotis Symeonidis*: Study of spatial and temporal variation of atmospheric optical parameters and their relation with PM 2.5 concentration over Europe using GIS technologies (2017).
67. *Michaela Bobeck:* A GIS-based Multi-Criteria Decision Analysis of Wind Farm Site Suitability in New South Wales, Australia, from a Sustainable Development Perspective (2017).
68. *Raghdaa Eissa*: Developing a GIS Model for the Assessment of Outdoor Recreational Facilities in New Cities Case Study: Tenth of Ramadan City, Egypt (2017).
69. *Zahra Khais Shahid*: Biofuel plantations and isoprene emissions in Svea and Götaland (2017).
70. *Mirza Amir Liaquat Baig*: Using geographical information systems in epidemiology: Mapping and analyzing occurrence of diarrhea in urban - residential area of Islamabad, Pakistan (2017).
71. *Joakim Jörwall*: Quantitative model of Present and Future well-being in the EU-28: A spatial Multi-Criteria Evaluation of socioeconomic and climatic comfort factors (2017).