ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΙΑΣ

ΤΜΗΜΑ ΟΙΚΟΝΟΜΙΚΩΝ ΣΠΟΥΔΩΝ

Η πορεία προς την κυκλική οικονομία: εξετάζοντας τις πολιτικές διαχείρισης αποβλήτων

ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

Υποψήφια διδάκτορας: Κλεονίκη - Ναταλία Πέτρου

Επιβλέπων καθηγητής: καθ. Γεώργιος Χάλκος

Βόλος

2019

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

This page was left blank intentionally.

UNIVERSITY OF THESSALY

Department Of Economics

UNIVERSITY OF THESSALY

DEPARTMENT OF ECONOMICS

Moving towards a circular economy: Evaluating waste management practices

DOCTORAL THESIS

Candidate's name: Kleoniki-Natalia Petrou

Supervisor's name: Professor George Halkos

Volos, Greece

2019

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

This page was left blank intentionally.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I.
Hellenic Foundation for Research & Innovation

UNIVERSITY OF THESSALY

Department Of Economics

Η παρούσα έρευνα έχει χρηματοδοτηθεί από τη Γενική Γραμματεία Έρευνας και Τεχνολογίας (ΓΓΕΤ) και το Ελληνικό Ίδρυμα Έρευνας & Καινοτομίας (ΕΛΙΔΕΚ).

This research has been financed by the General Secretariat for Research and Technology (GSRT) and the Hellenic Foundation for Research and Innovation (HFRI).

GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Table of Contents

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Acknowledgements

It is truly difficult to depict the difficulties, personal and professional, one has to go through, while pursuing a PhD, so I can only acknowledge all those people, that supported me during this journey.

First of all I would like to express my sincere gratitude to my supervisor Professor George Halkos for the continuous support of my PhD study and related research, for his patience, motivation, and immense knowledge. Besides my supervisor, I would like to thank the rest of my Thesis committee Dr Iakovos Psarianos and Professor Athanasios Koungolos for their help and support throughout this Thesis.

This PhD research could not have been attempted without financial support provided by the General Secretariat for Research and Technology (GSRT) and the Hellenic Foundation for Research and Innovation (HFRI), so thank you for this.

I have been extremely lucky having around me people that were always willing to help me, when asked. A very special thanks goes to my parents for their support, unconditional love and encouragement and especially for their academic advice and support throughout all my academic years.

Another special thanks goes to my husband, John, for bearing with me through this period and providing emotional support all this time and helping me lift myself up and continue. Last but not least, a huge thank you goes to my son, Vasilis, for enduring me in his first 15 months of life.

Table of figures

Table of tables

Abbreviations

AD	Anaerobic Digestion
ADF	Augmented Dickey-Fuller
APC	Air Pollution Control
CBA	Cost Benefit Analysis
CD	Cross sectional dependance
CLO	Compost-like-output
CPP	Probabilistic Composition of Preferences
CRS	Constant Returns to Scale
C&D	Construction and Demolition
C&I	Commercial and Industrial
DDF	Directional Distance Functions
DEA	Data Envelopment Analysis
DF	Dickey-Fuller
DMUs	Decision Making Units
EAP	Environmental Action Programmes
EC	European Commission
EKC	Environmental Kuznets Curve
EU	European Union
FE	Fixed Effects
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GMM	Generalised Method of Moments
GNI	Gross National Income
KPIs	Key Performance Indicators
IBA	Incinerator Bottom Ash
IDV	Individualism vs. Collectivism
IND	Indulgence vs. restraint
LCA	Lifecycle Assessement
LR	Likelihood Ratio

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

LTO	Long term vs. short term orientation
IMS	Integrated Modelling System
MAD	Mean Absolute Deviation
MAPE	Mean Absolute Percentage Error
MAS	Masculinity vs. Feminity
MBT	Mechanical biological treatment
MSD	Mean Squared Deviation
OLS	Ordinary Least Squares
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
OECD	Organisation for Economic Co-operation and Development
PDI	Power Distance Index
RDF	Refuse Derived Fuel
RE	Random Effects
SBM	Slacks-based measure
SCP	Sustainable consumption and production
SFA	Stochastic Frontier Analysis
SRF	Solid Recovered Fuel
THT	Trompenaars Hampden-Turner
VRS	Variable Returns to Scale
UAI	Uncertainty Avoidance Index
UNEP	United Nations Environment Programme
WFD	Waste Framework Directive
WVS	World Values Survey

Εκτεταμένη Περίληψη

Στη σημερινή εποχή τα απόβλητα αποτελούν ζωτικό μέρος της οικονομίας μας, ως υποπροϊόν της οικονομικής δραστηριότητας. Προέρχονται από τις επιχειρήσεις, την κυβέρνηση και τα νοικοκυριά και με τις κατάλληλες τεχνικές διαχείρισης, μπορούν να χρησιμοποιηθούν ως εισροή στην οικονομική δραστηριότητα, για παράδειγμα μέσω της ανάκτησης υλικών ή ενέργειας. Παράγονται από όλες τις δραστηριότητες και παρόλο που είναι ένα τοπικό πρόβλημα, έχει τόσο τοπικές όσο και παγκόσμιες διαστάσεις.

Σύμφωνα με την οδηγία-πλαίσιο 2008/98/ΕΚ της Ευρωπαϊκής Ένωσης (ΕΕ), «κάθε ουσία ή αντικείμενο που ο κάτοχος απορρίπτει ή προτίθεται ή υποχρεούται να απορρίψει ορίζεται ως απόβλητο». Επιπλέον, τα αστικά απόβλητα περιλαμβάνουν τα απόβλητα που συλλέγονται από ή για λογαριασμό των δημοτικών αρχών και διατίθενται μέσω των καθιερωμένων συστημάτων διαχείρισης αποβλήτων. Τα τελευταία χρόνια τα απορρίμματα συνεχώς αυξάνονται, επομένως η διαχείριση τους αναδεικνύεται ως ένα αρκετά μεγάλο ζήτημα του 21ου αιώνα και διεξάγονται αρκετές έρευνες στον τομέα αυτό.

Η παρούσα διδακτορική διατριβή θα ασχοληθεί με το θέμα των αστικών στερεών αποβλήτων (ΑΣΑ) και θα αξιολογήσει τις δυνητικές και τρέχουσες επιλογές διαχείρισης αποβλήτων καθώς και θα εξετάσει διάφορες πτυχές γύρω από αυτό το θέμα. Τόσο δεδομένα από την ΕΕ όσο και παγκόσμια θα χρησιμοποιηθούν και τόσο σε περιφερειακό όσο και σε εθνικό επίπεδο, ώστε να αντανακλούν καλύτερα τη σημερινή κατάσταση. Επίσης, τα πολιτιστικά χαρακτηριστικά των κρατών μελών της ΕΕ καθώς και η ενεργειακή απόδοση τους αξιολογούνται σε σχέση με τα ΑΣΑ. Τέλος, εξετάζεται η σχέση μεταξύ των ΑΣΑ και της εκπαίδευσης. Όλες αυτές οι ιδιότητες αξιολογούνται λαμβάνοντας υπόψιν την οικονομική κρίση, η οποία επηρέασε σοβαρά την ΕΕ και τον κόσμο ιδιαίτερα μετά το 2008, γεγονός που προφανώς επηρέασε με τη σειρά του και τις στάσεις και τις επιλογές των πολιτών.

Η αειφόρος διαχείριση των αποβλήτων απαιτεί τον συνδυασμό δεξιοτήτων και γνώσεων των φυσικών επιστημών και της μηχανικής μαζί με την οικονομία, την οικολογία, την ανθρώπινη συμπεριφορά, την επιχειρηματικότητα και τη σωστή διακυβέρνηση. Το πλαίσιο πολιτικών και το νομοθετικό πλαίσιο γύρω από τα ΑΣΑ αναλύεται σε αυτή τη διατριβή στο πλαίσιο της Κυκλικής Οικονομίας λαμβάνοντας υπόψη την αποτελεσματικότερη χρήση των πόρων.

Όσον αφορά την ανάλυση σε περιφερειακό επίπεδο της ΕΕ, αυτή γίνεται με τη χρήση της μεθόδου Data Envelopment Analysis (DEA). Η DEA είναι μια μη παραμετρική μέθοδος που χρησιμοποιείται για τη μέτρηση της απόδοσης ορισμένων μονάδων λήψης αποφάσεων χρησιμοποιώντας τεχνικές γραμμικού προγραμματισμού. Με την DEA μπορεί κανείς να μετρήσει τις επιδόσεις απόδοσης παρόμοιων μονάδων που έχουν πολλαπλές (συνήθως) εισροές και ανάλογες εκροές σε συνθήκες όπου υπάρχουν ακριβείς πληροφορίες για τις τιμές τους και καμία γνώση για τη μεταξύ τους σχέση.

Στο πρώτο μέρος της διδακτορικής διατριβής εξετάζονται 172 περιφέρειες της ΕΕ και για τα έτη 2009, 2011 και 2013 και χρησιμοποιούνται πέντε παράμετροι (παραγωγή αποβλήτων, ποσοστό απασχόλησης, σχηματισμός κεφαλαίου, ακαθάριστο εγχώριο προϊόν (ΑΕΠ) και πυκνότητα πληθυσμού). Έτσι σχεδιάζονται τέσσερα πλαίσια εισροών και εκροών. Τα αποτελέσματα δείχνουν τις πιο αποτελεσματικές περιφέρειες της ΕΕ ανάλογα με το κάθε πλαίσιο, αλλά πρέπει να σημειωθεί ότι τα αποτελέσματα από διαφορετικά πλαίσια δεν πρέπει να συγκρίνονται μεταξύ τους. Τα συνολικά αποτελέσματα δείχνουν ότι οι πιο αποδοτικές περιοχές είναι οι περιοχές του Βελγίου, της Ιταλίας, της Πορτογαλίας και του Ηνωμένου Βασιλείου.

Εν συνεχεία η αποτελεσματικότητα που προκύπτει από τη DEA επανεξετάζεται σε σχέση με τις επιλογές διαχείρισης αποβλήτων που εφαρμόζονται στις σχετικές περιοχές για την αξιολόγηση της συνολικής βιωσιμότητας των εξεταζόμενων περιφερειών. Σύμφωνα με τα συμπεράσματα, παρόλο που μια χώρα μπορεί να είναι αποτελεσματική σύμφωνα με τη DEA και λαμβάνοντας υπόψη διάφορους παράγοντες, αυτό δεν σημαίνει απαραίτητα ότι οι περιφέρειες μιας χώρας χρησιμοποιούν επιλογές βιώσιμης επεξεργασίας αποβλήτων, καθώς είναι σημαντικό να λαμβάνεται υπόψιν και η μεταφορά αποβλήτων μεταξύ περιφερειών και χωρών. Αυτά τα ευρήματα μπορεί όμως να αποδειχθούν πολύτιμα για τον σχεδιασμό περιβαλλοντικών πολιτικών, ειδικά σε περιφερειακό επίπεδο της ΕΕ.

Ένα περαιτέρω μέρος αυτής της διατριβής ασχολείται με την αποτελεσματικότητα 28 κρατών μελών της ΕΕ για τα έτη 2008, 2010, 2012 και 2014 με τη χρήση της μεθόδου DEA. Χρησιμοποιούνται οκτώ παράμετροι, δηλαδή η παραγωγή ΑΣΑ, το ποσοστό απασχόλησης, ο σχηματισμός κεφαλαίου, το ΑΕΠ, η πυκνότητα του πληθυσμού και για πρώτη φορά εκπομπές οξειδίων του θείου (SOx), οξειδίων του αζώτου (NOx) και αερίων του θερμοκηπίου (GHG). Τα εμπειρικά αποτελέσματα που προέκυψαν υποβλήθηκαν σε διόρθωση μεροληψίας προκειμένου να ληφθούν τα σωστά αποτελέσματα για κάθε χώρα που μελετήθηκε. Συνολικά, οι πιο αποδοτικές χώρες αποδείχτηκαν ότι ήταν η Γερμανία, η Ιρλανδία και το Ηνωμένο Βασίλειο. Αυτά τα αποτελέσματα εξετάστηκαν εν συνεχεία έναντι του ποσοστού ανακύκλωσης κάθε χώρας για τις εξεταζόμενες χρονικές περιόδους. Το ποσοστό ανακύκλωσης αντικατοπτρίζει τα αποτελέσματα της DEA, και μάλιστα οι πιο αποτελεσματικές χώρες φαίνεται να έχουν υψηλότερο ποσοστό ανακύκλωσης. Επιπλέον, τα αποτελέσματα της DEA εξετάστηκαν με τις συνολικές μεθόδους διαχείρισης αποβλήτων για τις υπό εξέταση χώρες.

Συνολικά, παρατηρείται ότι οι χώρες που χρησιμοποιούν και τις τέσσερις επιλογές διαχείρισης με υψηλή χρήση πιο βιώσιμων και τη μείωση της χρήσης χώρων υγειονομικής ταφής είναι αυτές που αποδείχθηκαν επίσης αποτελεσματικές σύμφωνα με την DEA. Τα αποτελέσματα αντικατοπτρίζουν και την οικονομική κρίση που έπληξε την Ευρώπη, η οποία προσπάθησε να επωφεληθεί από τις βιώσιμες επιλογές διαχείρισης ΑΣΑ προκειμένου να επιτευχθεί η μετάβαση σε μια κυκλική οικονομία, ενώ η αξία των προϊόντων, των υλικών και των πόρων πρέπει να διατηρηθεί στην οικονομία όσο το δυνατόν περισσότερο και η παραγωγή αποβλήτων να ελαχιστοποιείται. Η συγκεκριμένη μελέτη μπορεί να αποτελέσει πολύτιμο μάθημα για τους υπεύθυνους χάραξης πολιτικής όσον αφορά το σχεδιασμό και την εφαρμογή εθνικών και κοινοτικών νομοθεσιών και οδηγιών, προκειμένου να επιτευχθούν οι στόχοι για μια Ευρώπη με κυκλική οικονομία.

Επιπλέον, τα ΑΣΑ αξιολογούνται μέσω των πολιτιστικών διαστάσεων και του σχηματισμού μιας «κουλτούρας αποβλήτων». Η ανάλυση αυτή αξιολογεί πρώτα την περιβαλλοντική αποτελεσματικότητα με τη DEA βάσει πέντε παραμέτρων: τα ΑΣΑ, το ΑΕΠ, το εργατικό δυναμικό, το κεφάλαιο και τη πυκνότητα πληθυσμού για 22 κράτη μέλη της ΕΕ και για τα έτη 2005, 2010 και 2015, προκειμένου να αξιολογηθεί ποια κράτη μέλη είναι πιο αποτελεσματικά. Στη συνέχεια, τα αποτελέσματα απόδοσης αντιπαραβάλλονται με τις πολιτιστικές διαστάσεις του Hofstede και του Schwartz στο STATA με τη χρήση μοντέλων παλινδρόμησης.

Τα αποτελέσματα δείχνουν ότι για το έτος 2005 δεν παρατηρείται σημαντική σχέση με τα δύο πολιτιστικά μοντέλα, ενώ για τα έτη 2010 και 2015 φαίνεται να υπάρχει σημαντική σχέση. Τα προαναφερθέντα ευρήματα μπορούν να συνδεθούν και πάλι με την οικονομική κρίση που έπληξε την Ευρώπη μετά το 2008, καθιστώντας τους ανθρώπους πιο επιφυλακτικούς, ενώ οι νομοθεσίες της ΕΕ έχουν θεσπίσει ορισμένες σημαντικές οδηγίες στον τομέα της διαχείρισης αποβλήτων. Τέλος, παράλληλα με τους προαναφερθέντες παράγοντες, η ΕΕ αντιμετώπισε σοβαρές περιβαλλοντικές προκλήσεις λόγω της δημιουργίας αποβλήτων, καθώς και ατυχημάτων και τραυματισμών των

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

εργαζομένων στον τομέα αυτό, οι οποίοι με τη σειρά τους έχουν επηρεάσει ευρέως την κουλτούρα αποβλήτων της ΕΕ, όπως υποστηρίζουν και τα αποτελέσματα της παρούσας ανάλυσης.

Επιπροσθέτως, η διατριβή εξετάζει την ενεργειακή απόδοση σε 28 επιλεγμένα κράτη μέλη της ΕΕ και τις δυνατότητες ανάκτησης ενέργειας από τα απόβλητα σύμφωνα με τις αποτελεσματικότητες που έχουν αποκτηθεί μέσω της μεθόδου DEA και χρησιμοποιούνται οι ακόλουθες μεταβλητές ως εισροές: τελική κατανάλωση ενέργειας, εργατικό δυναμικό, κεφάλαιο, πυκνότητα πληθυσμού και εκροές: ΑΕΠ, εκπομπές NOx, εκπομπές SOx και εκπομπές αερίων του θερμοκηπίου για τα έτη 2008, 2010, 2012, 2014 και 2016. Τα αποτελέσματα δείχνουν ότι οι περισσότερες χώρες διατηρούν τα επίπεδα αποτελεσματικότητας τους, ενώ παράλληλα οι περισσότερες αποτελεσματικότητες μειώνονται μετά το 2012.

Με βάση αυτές τις αποτελεσματικότητες, συνιστάται να προχωρήσουμε προς την παραγωγή ενέργειας μέσω αποβλήτων με δύο κύριους στόχους, δηλαδή την επαρκή και βιώσιμη παραγωγή ενέργειας και την αποτελεσματική αντιμετώπιση των ΑΣΑ. Μια τέτοια επιλογή θα ενίσχυε την κυκλική οικονομία, ενώ πρέπει να δοθεί προτεραιότητα στην πρόληψη, προετοιμασία για επαναχρησιμοποίηση, την ανακύκλωση και την ανάκτηση ενέργειας των ΑΣΑ. Μαζί με τη στρατηγική ανταγωνισμού της Ευρωπαϊκής Επιτροπής, αυτές οι πολιτικές θα εξασφαλίσουν αξιόπιστο ενεργειακό εφοδιασμό σε λογικές τιμές και με τις λιγότερες περιβαλλοντικές επιπτώσεις. Επιπλέον, οι αποτελεσματικότητες πρέπει να εξεταστούν και συγκριτικά με τη χρηματοοικονομική κρίση που πλήττει την ΕΕ από το 2008, όπου φαίνεται και μείωση των αποτελεσματικοτήτων μετά το 2012 και την πιο επικείμενη κρίση.

Τέλος, η εκπαίδευση έχει αποδειχθεί ότι συνδέεται στενά με το ποσό παραγωγής των ΑΣΑ. Το τελευταίο μέρος της παρούσας διατριβής χρησιμοποιεί δεδομένα που αποκτήθηκαν για 25 χώρες παγκοσμίως για τα έτη 1995-2016 και οι εξεταζόμενες μεταβλητές περιλαμβάνουν τα ΑΣΑ, το ΑΕΠ και το επίπεδο εκπαίδευσης. Μέσω οικονομετρικών μεθόδων, η παρούσα ανάλυση προσπαθεί να ανακαλύψει εφικτές σχέσεις συσχέτισης. Επίσης, δείχνει έντονα την αλληλεξάρτηση μεταξύ ΑΣΑ, οικονομικής ανάπτυξης και επιπέδου εκπαίδευσης. Βάσει αυτών επαληθεύεται η εγκυρότητα της υπόθεσης της περιβαλλοντικής καμπύλης Kuznets. Συγκεκριμένα, παρατηρείται μια ανεστραμμένη σχέση σχήματος U τόσο στις στατικές όσο και στις δυναμικές αναλύσεις για τα ΑΣΑ. Τα υπολογιζόμενα σημεία καμπής αν και αρκετά υψηλά είναι σε όλες τις περιπτώσεις μέσα στο δείγμα. Σε όλες τις αναλύσεις το πρόσημο του επιπέδου εκπαίδευσης είναι αρνητικό όπως αναμενόταν. Ως εκ τούτου,

GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

αποδεικνύεται ότι η εκπαίδευση μπορεί να λειτουργήσει ως αποτελεσματικό εργαλείο για την ενίσχυση των περιβαλλοντικών συμπεριφορών που οδηγούν με τη σειρά τους σε μείωση της παραγωγής ΑΣΑ.

Φυσικά, δεδομένου ότι τα δεδομένα και η μεθοδολογία που χρησιμοποιούνται σε αυτές τις αναλύσεις είναι διαφορετικά, τα ίδια τα αποτελέσματα δεν μπορούν να συγκριθούν, αλλά είναι φανερό ότι η τρέχουσα οικονομική και πολιτική κατάσταση τόσο στην ΕΕ όσο και παγκοσμίως έχει επηρεάσει την ανάπτυξη του τομέα των ΑΣΑ και της συμπεριφοράς των ανθρώπων. Αυτό κατέστη εμφανές σε όλες τις προσεγγίσεις, είτε το επίκεντρο αφορούσε τα ίδια τα ΑΣΑ είτε τις πολιτιστικές διαστάσεις ή την ενεργειακή απόδοση, είτε την εκπαίδευση.

Executive Summary

Nowadays waste has become a vital part of our economy, as a by-product of economic activity. It originates from businesses, the government and households and following appropriate management techniques, it can be used as an input to economic activity for instance through material or energy recovery. Waste is produced by all activities and although it is a locally arising problem it has both local and global effects.

According to the European Union (EU) Waste Framework Directive 2008/98/EC, 'any substance or object which the holder discards or intends or is required to discard is defined as waste'. In addition municipal waste consists of waste collected by or on behalf of municipal authorities and disposed of via established waste management systems. Waste arisings have been increasing over the past few years, hence their management has proved to be a rather challenging issue in the 21st century and a lot of research is being conducted in this field.

This Thesis will deal with the issue of Municipal Solid Waste (MSW) and will evaluate potential and current waste management options as well as examine various aspects around this topic. Both EU and worldwide data will be employed in those regards and both at regional and country levels in order to better reflect today's situation. Also the cultural characteristics of EU Member States as well as energy efficiency are assessed in relation to MSW. Finally the relationship between MSW arisings and education is examined. All these attributes are evaluated taking the financial crisis into account that has affected the EU and the world severely especially since 2008, which obviously has influenced people's attitudes and treatment options.

Sustainable waste management requires the combination of skills and knowledge of physical sciences and engineering together with economics, ecology, human behaviour, entrepreneurship and good governance. The policy framework and the legislative background around MSW is discussed in this Thesis under the Circular Economy approach having in mind the idea of closing the loop and hence achieving a more efficient use of resources.

With regards to the regional level EU analysis, this is conducted with the use of Data Envelopment Analysis (DEA). DEA is a non-parametric approach that is used to measure the efficiency of certain Decision Making Units (DMUs) by employing linear programming techniques. With DEA one can measure the efficiency performances of comparable DMUs which have multiple (usually) inputs and likewise outputs in conditions where there is accurate information on their values and no knowledge about their relationship.

In this specific analysis both good and bad outputs are taken into account and different frameworks are designed. Five parameters (waste generation, employment rate, capital formation, Gross Domestic Product (GDP) and population density) are used for 172 EU regions and for the years 2009, 2011 and 2013. In this way four frameworks have been designed, each with different inputs and outputs. The results show the most efficient EU regions according to each framework, but it should be noted that results from different frameworks should not be compared with each other.

Results suggest that the highest performers are regions in Belgium, Italy, Portugal and the UK. Finally, the efficiency results from DEA are reviewed against the treatment options employed in the relevant regions to assess overall sustainability of the regions examined. Findings show that, although a country might be efficient according to DEA and by taking various factors into consideration, this does not necessarily mean that regions within a country use sustainable waste treatment options, as it is essential to account for trade and shipment of waste between regions and countries as well. These findings may prove valuable for the planning of environmental policies, especially on an EU regional level.

A further part of this Thesis deals with the efficiency of the 28 EU Member States for the years 2008, 2010, 2012 and 2014 by DEA. Eight parameters are used, namely MSW generation, employment rate, capital formation, GDP, population density and for the first time sulphur oxide (SOx), nitrogen oxide (NOx) and greenhouse gases (GHG) emissions from the waste sector for the relevant countries. The empirical results obtained were bias corrected in order to get the correct efficiency scores for each country studied. Overall the most efficient countries were shown to be Germany, Ireland and the UK. These results were then reviewed against the recycling rate of each country for the examined time periods. The recycling rate actually depicts the DEA results, namely more efficient countries seem to have a higher recycling rate too. Moreover the DEA efficiency results were contrasted to the overall treatment options used in the countries under consideration.

It is noticed that countries employing all four treatment options with high use of more sustainable ones and decrease in the use of landfill are the ones that also proved to be efficient according to DEA. These results resemble the image of a financial crisis hit Europe which tried to take advantage of the more sustainable treatment options in order to achieve a transition to a circular economy, whereas the value of products, materials and resources needs to be maintained in the economy for as long as possible and the generation of waste minimised. This can be a valuable lesson for policy makers in the design and application of national and EU legislations and directives in order to achieve also the targets towards a circular economy driven Europe.

Furthermore MSW is assessed through the lense of cultural dimensions and the formation of a 'waste culture'. This analysis first evaluates environmental efficiency with DEA based on five parameters: waste, GDP, labour, capital and population density for 22 EU Member States and for the years 2005, 2010 and 2015 in order to evaluate which Member States are more efficient. Then the efficiency results are contrasted to Hofstede's and Schwartz's cultural dimensions on STATA with the use of regression modelling. Results show that for year 2005 no significant relationship is noticed for both cultural models, whereas for years 2010 and 2015 there appears to be a significant connection.

The above-mentioned findings can again be associated with the financial crisis that has hit Europe after 2008 making people more sceptical, while EU legislations have laid out some important directives in the field of waste management. Finally, along with the factors above, EU has faced severe environmental challenges due to waste arisings, as well as accidents and injuries for people working in this sector, which in turn have widely modified EU's waste culture as supported by this analysis' results.

Moreover this Thesis examines energy efficiency across 28 selected EU Member States and reviews the potential for energy recovery from waste according to the efficiency scores obtained. The efficiencies are assessed through DEA and the following variables are used, inputs: final energy consumption, labour, capital, population density and outputs: GDP, NOx emissions, SOx emissions and GHG emissions for the years 2008, 2010, 2012, 2014 and 2016. Results show that most countries maintain their efficiency scores with only a few marginally improving theirs and at the same time, it is noticed that most are decreasing after 2012.

Based on these efficiency scores, it is recommended to move towards waste-to-energy with two main objectives, namely sufficient and sustainable energy production and effective treatment of MSW. This option would enhance the circular economy, whereas prioritization needs to be given to prevention, preparation for reuse, recycling and energy recovery through to disposal. Together with the EU Commission's competition strategy, these would ensure reliable energy supplies at rational prices and with the least environmental impacts. Moreover the efficiency scores need to be examined along the financial crisis which has been affecting the EU since 2008, showing a decrease in those efficiency scores after 2012 under a more imminent crisis.

Finally education has been shown to be closely related to the amount of MSW generated. The last part of this Thesis uses panel data obtained for 25 world counties for the years 1995-2016 and the examined variables include MSW, GDP and education level. Through econometric methods, the present analysis accounts for the presence of cross section dependence and uses appropriate panel unit root tests to discover feasible cointegrated relationships. Also it strongly accounts for the interdependence between MSW, economic growth and education level. Based on these, the validity of the Environmental Kuznets Curve (EKC) hypothesis is redefined. Specifically, an inverted U-shape relationship is observed both in the static and dynamic analyses for MSW. The calculated turning points although quite high they are in all cases within the sample. In all specifications the sign of education level is negative as expected. Therefore it is shown that education can act as an effective tool to enhance pro-environmental behaviours leading in turn to lower MSW arisings.

Of course as the data and methodology used in these analyses are different the results themselves cannot be contrasted, but it is apparent that the current financial and political situation both in EU and worldwide has affected the development of the MSW sector and people's attitudes as well. This was evident through all approaches whether the focus was on MSW itself or cultural dimensions or energy efficiency or even education.

Main contributions

- This Thesis examined the issue of Municipal Solid Waste (MSW) management and potential management implications under the notion of the circular economy for EU and worldwide data, taking in each case different parameters and years into consideration. Specifically the focus was:
    - Efficiency of MSW arisings for EU regions.
    - Efficiency of MSW arisings for EU countries.
    - Cultural indicators (based on Hofstede's and Schwartz' models) and correlation to MSW arisings for EU countries.
    - Energy efficiency of EU countries and potential use of waste-to-energy options.
    - Relationship between education and MSW for OECD countries with the use of panel data.
- Employing Data Envelopment Analysis (DEA) for four out of the five cases, this Thesis accounted for the existence of Constant Returns vs Variable Returns of Scale, bias in the estimators and the treatment of undesirable outputs of our data.
    - Results from the DEA efficiency analysis for EU countries and regions were contrasted to the treatment options of MSW and the recycling rate of the examined units and it was found that those ones that employ more sustainable treatment options (such as composting, incineration, recycling) have higher efficiency scores as well.
    - The correlation between the DEA results for the third case and the cultural indicators was examined and it was found that there is no significant relationship for 2005, but for 2010 and 2015 these are highly correlated. This can be linked to the financial crisis which has affected the EU especially since 2008 making people more skeptical on environmental issues.
    - For the fourth case, it was found that energy efficiency scores across EU were quite low overall, thus the use of waste-to-energy treatment options seems like a feasible potential especially under the new EU directives for a climate neutral Europe.
    - Finally the relationship between education and MSW was examined for OECD panel data and it was found that education highly affects the production of MSW. Therefore education can act as an effective tool to enhance pro-environmental behaviours leading in turn to lower MSW arisings. Also the existence of an Environmental Kuznets Curve (EKC) is validated in this analysis.
- Overall all this research showed that the financial crisis has undoubtedly affected people's attitudes and behaviour towards MSW management.
- Under the circular economy, resources need to be maintained into the economy for as long as possible to create more value and this in turn would also enhance the use of more sustainable treatment options for MSW and increase energy reuse and production.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Κύριες συνεισφορές

- Η παρούσα διδακτορική διατριβή εστίασε στο θέμα της διαχείρισης των αστικών στερεών αποβλήτων (ΑΣΑ) και τις ενδεχόμενες επιπτώσεις της διαχείρισης τους, υπό το πρίσμα της κυκλικής οικονομίας για δεδομένα από την ΕΕ αλλά και παγκόσμια, λαμβάνοντας υπόψη διαφορετικές παραμέτρους και έτη. Συγκεκριμένα εξέτασε τα παρακάτω:
    - Αποτελεσματικότητα της δημιουργίας ΑΣΑ για τις περιφέρειες της ΕΕ.
    - Αποτελεσματικότητα της δημιουργίας ΑΣΑ για τις χώρες της ΕΕ.
    - Πολιτιστικούς δείκτες (με βάση τα μοντέλα του Hofstede και Schwartz) και τα συσχέτισε με την δημιουργία ΑΣΑ για τις χώρες της ΕΕ.
    - Ενεργειακή απόδοση των χωρών της ΕΕ και δυνατότητα παραγωγής ενέργειας από τα απόβλητα.
    - Σχέση μεταξύ εκπαίδευσης και ΑΣΑ για τις χώρες του ΟΟΣΑ με τη χρήση διαστρωματικών δεδομένων.
- Χρησιμοποιώντας τη μέθοδο Data Envelopment Analysis (DEA) για τέσσερις από τις πέντε περιπτώσεις, η παρούσα διδακτορική διατριβή εξετάζει την ύπαρξη σταθερών έναντι μεταβλητών αποδόσεων κλίμακας, τη μεροληψία στους εκτιμητές και τη χρήση ανεπιθύμητων εκροών στα δεδομένα που χρησιμοποιήθηκαν.
    - Από την ανάλυση για τις χώρες και τις περιφέρειες της ΕΕ, οι αποτελεσματικότητες συγκρίθηκαν με τις μεθόδους διαχείρισης των ΑΣΑ και το ποσοστό ανακύκλωσης και διαπιστώθηκε ότι αυτές που χρησιμοποιούν πιο βιώσιμες μεθόδους (όπως κομποστοποίηση, αποτέφρωση, ανακύκλωση) έχουν και υψηλότερα σκορ αποτελεσματικότητας.
    - Η συσχέτιση μεταξύ των αποτελεσμάτων της DEA και των πολιτιστικών δεικτών εξετάστηκε και διαπιστώθηκε ότι δεν υπάρχει σημαντική σχέση για το 2005, αλλά για το 2010 και το 2015 υπάρχει ισχυρή συσχέτιση. Το συγκεκριμένο εύρημα μπορεί να συνδεθεί με τη χρηματοπιστωτική κρίση που επηρέασε την ΕΕ ιδιαίτερα από το 2008, καθιστώντας τους ανθρώπους πιο σκεπτικούς πάνω σε περιβαλλοντικά ζητήματα.
    - Για την τέταρτη περίπτωση, διαπιστώθηκε ότι τα σκορ ενεργειακής αποδοτικότητας σε ολόκληρη την ΕΕ ήταν συνολικά χαμηλά, οπότε η χρήση μεθόδων για παραγωγή ενέργειας από τα απόβλητα φαίνεται να αποτελεί μια καλή εναλλακτική, ιδίως σύμφωνα με τις νέες οδηγίες της ΕΕ για μια ουδέτερη κλιματικά Ευρώπη.
    - Τέλος, εξετάστηκε η σχέση μεταξύ εκπαίδευσης και ΑΣΑ και διαπιστώθηκε ότι η εκπαίδευση επηρεάζει ιδιαίτερα την παραγωγή ΑΣΑ. Ως εκ τούτου, μπορεί να λειτουργήσει ως αποτελεσματικό εργαλείο για την ενίσχυση των περιβαλλοντικών συμπεριφορών που οδηγούν με τη σειρά τους σε μείωση των αποβλήτων. Επίσης, στην παρούσα ανάλυση επιβεβαιώνεται η ύπαρξη περιβαλλοντικής καμπύλης Kuznets (EKC).
- Συνολικά όλες αυτές οι αναλύσεις έδειξαν ότι η χρηματοπιστωτική κρίση έχει επηρεάσει αναμφισβήτητα τη συμπεριφορά και τις στάσεις των ανθρώπων ως προς τη διαχείριση των ΑΣΑ.
- Στο πλαίσιο της κυκλικής οικονομίας, οι πόροι πρέπει να διατηρηθούν στην οικονομία όσο το δυνατόν περισσότερο για να έχουν περισσότερη αξία και αυτό με τη σειρά του θα ενισχύσει επίσης τη χρήση πιο βιώσιμων εναλλακτικών τρόπων επεξεργασίας για τα ΑΣΑ και θα αυξήσει την επαναχρησιμοποίηση και την παραγωγή ενέργειας από τα απόβλητα.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

1. Introduction

Nowadays waste has become a vital part of our economy, being a by-product of economic activity and originating from businesses, the government and households; at the same time it can be used as an input to the economic activity for instance through material or energy recovery (Defra, 2011a). More than one billion metric tons of Municipal Solid Waste (MSW) are currently thrown away worldwide annually and it is predicted that this number will reach 2.2 billion by 2025 (Hoornweg and Bhada-Tata, 2012).Waste arisings have been increasing over the past few years, hence their management has proved to be a rather challenging issue in the 21st century and a lot of research is being conducted in this field.

First of all, it is important to define waste in order to be able to manage it successfully. According to the European Union (EU) Waste Framework Directive 2008/98/EC, 'any substance or object which the holder discards or intends or is required to discard is defined as waste'. In addition municipal waste consists of waste collected by or on behalf of municipal authorities and disposed of via established waste management systems. The waste sector has conventionally referred to MSW excluding "wastewater", which is considered under the water or industry sectors (UNEP, 2011). Therefore it is important to note that MSW excludes the following waste streams: waste from sewage treatment, construction and demolition activities. MSW consists primarily of waste generated by households, although it also includes waste from sources (and of similar composition) such as commercial and industrial waste (Eurostat, 2014a).

The production of MSW is unavoidable due to human activity and its management affects human and environmental health (Vergara and Tchobanoglous, 2012). Rapid population growth and urbanization are noticed in recent years with an estimated 66% of the world's population living in cities by 2025 (Troschinetz and Mihelcic, 2009). These two trends also lead to the increase of waste around the world and consequently tend to concentrate more waste in the cities (Vergara and Tchobanoglous, 2012).

Every country produces different amounts of MSW and with different composition. This is because waste generated is influenced by the degree of urbanisation, patterns of consumption, household revenue and lifestyles in each country (Eurostat, 2014a). For instance there is a strong link between affluence and waste generation, despite of improvements in efficiency nowadays (World Bank, 1999). The amount of MSW generated per inhabitant (waste per capita) can prove valuable in capturing the potential environmental and health impacts, for example through soil and water contamination or poor air quality (Eurostat, 2014b).

Diverse technologies, policies and behaviours are being employed worldwide to control the negative effects of waste and find ways to reuse it efficiently; this combination of methods constitutes waste management (Vergara and Tchobanoglous, 2012). Waste management practices differ in developed and developing nations, in urban and rural areas and in residential and industrial producers (Magutu and Onsongo, 2011). Not only does the composition of waste vary between cities, it varies within a city over time (Vergara and Tchobanoglous, 2012). The four main drivers towards the development of waste management plans are: public health, environmental protection, resource recovery and climate change (Wilson, 2007).

Market failures exist in the economic markets and these prevent economic agents from making optimal choices, ultimately leading to an overproduction of waste; environmental externalities are one of the primary market failures – whereas economic decisions do not account for the environmental impacts of waste generated (Defra, 2011a). Further market failures and obstacles in the market are: imperfect information, imperfect competition or other barriers relating to efficiency such as excess planning costs, lack of access to credit and long payback periods (Defra, 2011a).

The treatment options of MSW can be classified in broad terms as: landfill, incineration, recycling and composting (Kungolos, 2016). Sustainable Waste Management is one of the most challenging issues faced by both developed and developing countries which are now trying to meet pressure from national and international communities to reduce their environmental impacts overall (Aravossis et al., 2001). Developed countries are examining how to avoid waste going to landfill and increase the recycling and recovery of materials. An important driver to this notion is the Waste Hierarchy (Figure 1). This gives top priority in preventing waste in the first place. Even when waste is finally created, priority is given in preparing it for re-use, then recycling, then recovery and as a last resort disposal (i.e. landfill) (Defra, 2011b).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

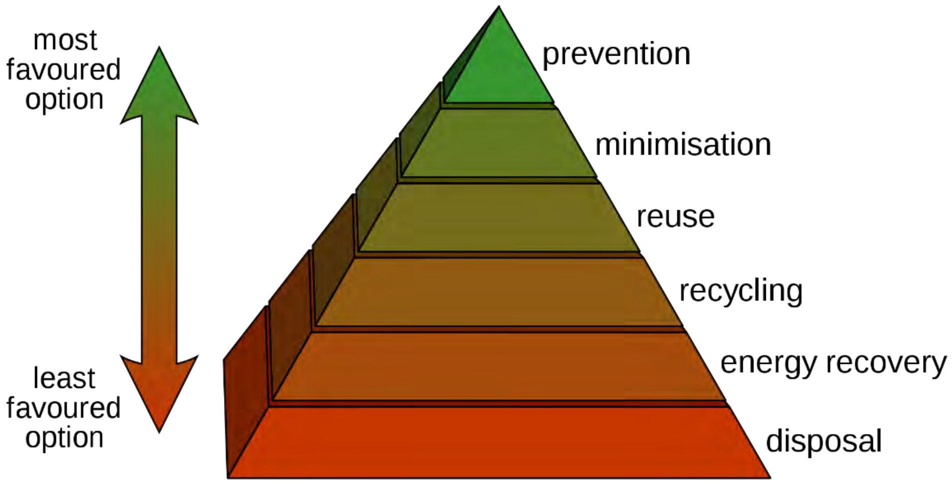


Figure 1: Waste hierarchy (Defra, 2011b)

Member States of the EU are bound by a number of Directives to not only reduce the amount of MSW going to landfill but also to increase its recoverability through recycling. Namely the European Commission Landfill Directive (99/31/EC) states that Member States need to reduce the amount of biodegradable municipal waste (BMW) sent to landfill to 35% of the 1995 levels, whereas the revised Waste Framework Directive (2008/98/EC) requires a 50% recycling rate for household waste and waste of similar nature to household by 2020.

Moreover in 2011, the European Commission launched an important initiative entitled 'A resource-efficient Europe' which supports the shift towards a resource-efficient, low-carbon economy with the ultimate goal to achieve sustainable growth (Eurostat, 2014a). Whether it is re-used, recycled, incinerated or put into landfills, the management of MSW brings in financial and environmental costs (European Commission, 2010a). The main issue around waste is that one cannot manage it, unless one measures it appropriately.

Nowadays the waste sector has been facing four major challenges: 1) increasing amounts and complexity of waste streams, 2) increasing risk of human health and ecosystems' impacts, 3) economic unpleasantness to use the 3Rs (Reduce, Recycle, Reuse) and 4) the sector's overall influence on climate change (UNEP, 2011).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

At the same time the following opportunities arise: 1) growth of the waste market, including demand for better waste management and use of recycled products 2) increasing scarcity of natural resources and the resulting rise in commodity prices and 3) emergence of new and improved waste management technologies (UNEP, 2011). Therefore this sector provides a great pool of research and is already creating a new business area worth investigating and developing further.

Therefore this Thesis focuses on MSW and presents the case for EU and worldwide data. On the EU level both the regional and country level data are taken into account in order to examine the relevant environmental efficiencies. Also the cultural characteristics of EU Member States as well as energy efficiency are assessed in relation to MSW. Finally the relationship between MSW arisings and education is examined. All these attributes are evaluated taking the financial crisis that has affected the EU and the world severely especially since 2008, which obviously has influenced people's attitudes and treatment options used as well.

Based on the examined literature, the aim of this Thesis is to identify the current situation of MSW arisings and their management under the notion of the circular economy. In achieving this aim the following objectives will be met as well:

- Assessment of the current situation regarding MSW management and relevant environmental efficiency.
- Identification of existing and potential waste management options.
- The results of this analysis are analysed taking the financial crisis into consideration and possible societal and policy implications.
- Suggestions are provided for the fulfilment of a real circular economy in EU Member States in accordance to the EU regulations and programmes, as well as potential policy implications for worldwide data.

The flowchart below (Figure 2) presents the main steps of the methodology that will be analysed further in Section 3 as well as how this research fulfilled the objectives mentioned above.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

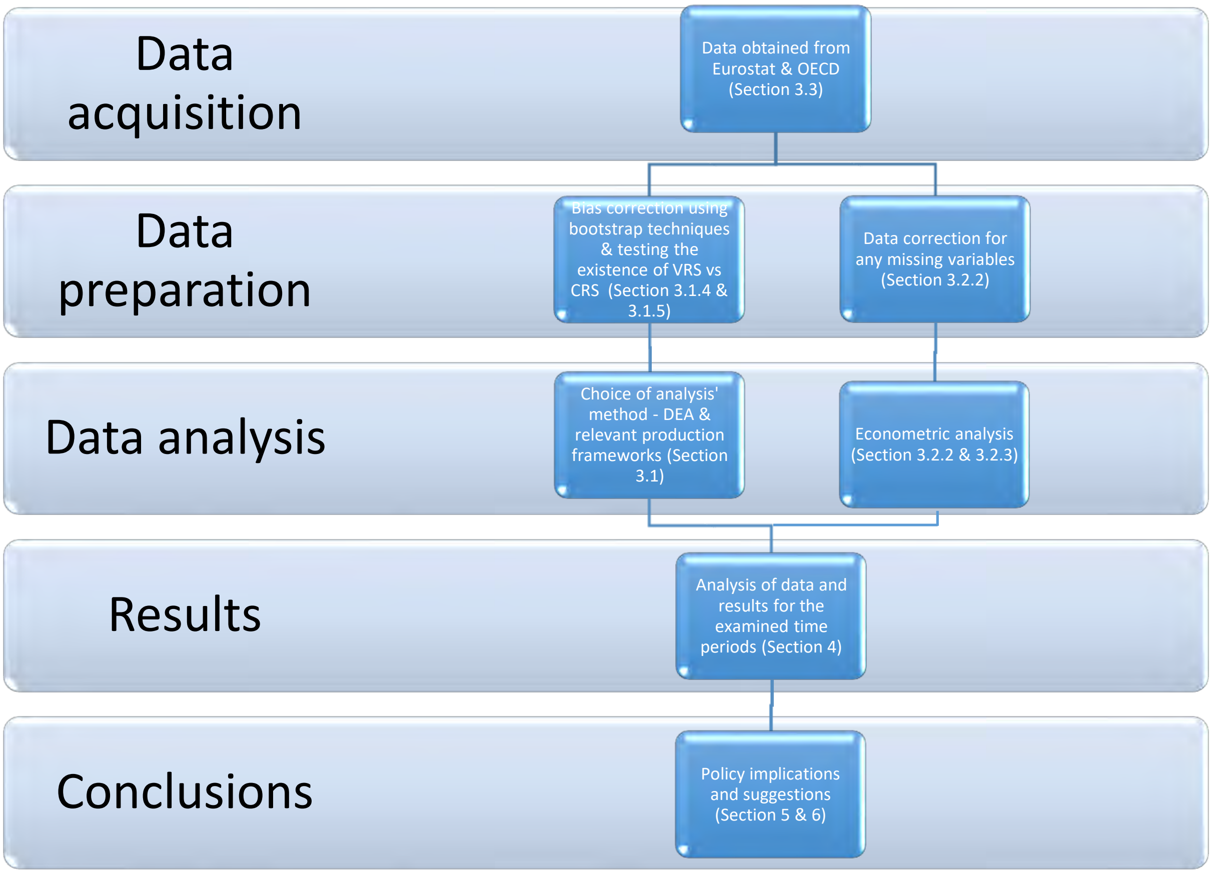


Figure 2: Flowchart of the present Thesis

Thus this Thesis contributes to the current literature by analysing the current situation and providing the relevant policy implications as well. Through this approach it is then possible to evaluate where its country/region is at present and what could be done to improve the situation on an environmental level. This is especially important considering the circular economy where all materials ought to be reused and reintroduced into the economy thus avoiding the loss of valuable resources.

The present Thesis is structured as follows, Section 2 presents the current state of the art and a solid background on the various aspects of the topic of the Thesis. In more detail Section 2.1 presents the policy framework and legislative background around MSW. Section 2.2 refers to the MSW arisings themselves and their composition while Section 2.3 presents the main treatment options of MSW. Additionally Section 2.4 shows the main aspects of MSW under the circular economy with Section 2.5 specialising on energy efficiency and MSW under the latter concept. Section 2.6 examines another

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

feature of MSW and waste management, namely the importance of culture and cultural characteristics in the formulation of a 'waste culture', therefore this section presents the main models depicting cultural dimensions. Finally Section 2.7 examines the possible relationship between MSW and education. Additionally Section 3 presents the proposed methodology, with Section 3.1 dealing with Data Envelopment Analysis (DEA) and Section 3.2 with econometric methods and panel data. Then Section 3.3 introduces the data of the present research.

Moreover Section 4 analyses the results of the present work, with Section 4.1 presenting the case of the EU regional analysis and Section 4.2 the case of the EU country level analysis. In addition Section 4.3 focuses on cultural dimensions and the formulation of 'waste culture' with Section 4.4 dealing with energy efficiency and MSW. Finally Section 4.5 presents the results of the research on MSW and education through panel data.

In relation to those results Section 5 discusses the implications of those on an EU and worldwide level as well as relevant policy implications. To conclude the work, Section 6 presents the main findings of the research (Section 6.1) as well as its limitations and suggestions for future work (Section 6.2).

2. Background

As mentioned previously and to start with the policy framework and legislative background are outlined (Section 2.1). At the same time, this section provides an overview of the waste sector both in terms of its composition (Section 2.2) and infrastructure (Section 2.3). Moreover the notion of the circular economy is introduced in Section 2.4, as well as the energy efficiency of the sector in terms of the circular economy (Section 2.5). Cultural dimensions that affect the formulation of a 'waste culture' are analysed and the main models dealing with these are presented in Section 2.6. Finally Section 2.7 presents the main points around education level and MSW.

2.1 Policy framework and legislative background

From its founding in 1957 until today, the European Union has managed to develop the most integrated environmental policy framework in the world through the six Environmental Action Programmes (EAP), under which several strategies and policies have been deployed (ISWM-Tinos, 2012). The 6th EAP and the thematic strategies on waste prevention and recycling and on natural resources particularly, evolves around the notion of *'to become a recycling society that seeks to avoid waste and uses waste as a resource'* (ISWM-Tinos, 2012).

The main legislation in the EU environmental policy is the Waste Framework Directive (WFD) which provides the legal framework on how to treat waste within the Community with the aim to protect the environment and human health through the prevention of the harmful effects of waste generation and waste management (European Commission, 2008). As stated in Article 2 of the Directive called 'Exclusions from the scope', it applies to waste excluding the following: gaseous effluents, radioactive elements, decommissioned explosives, faecal matter, waste waters, animal by-products, carcasses of animals that have died other than by being slaughtered, elements resulting from mineral resources (European Commission, 2008). Apart from this, the main elements forming the waste legislative background in the EU include the following (European Commission, 2015a):

- Directive 2006/12/EC on waste has been revised in order to be more up-to-date and restructure its provisions, therefore in the revised Directive 2008/98/EC (WFD) the basic concepts and definitions related to waste management are established and new waste management principles such as the "polluter pays principle" or the "waste hierarchy" are outlined as well (European Commission, 2015b). WFD or Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste. It provides the general context of the waste management requirements and establishes the basic definitions around waste management for the EU. Within the WFD there are specific provisions for each waste stream and how it should be managed.

- European Union legislation on waste management operations, which includes Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste and Directive 2000/59/EC of the European Parliament and of the Council of 27 November 2000 on port reception facilities for ship-generated waste and cargo residues.
- Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste. This one specifies the details regarding the shipment of waste between countries.
- Decision 2000/532/EC which sets a list of wastes. This Decision establishes the classification system for waste, including but not limited to a distinction between hazardous and non-hazardous wastes.

All relevant EU regulations in relation to waste management are presented schematically in Figure 3.

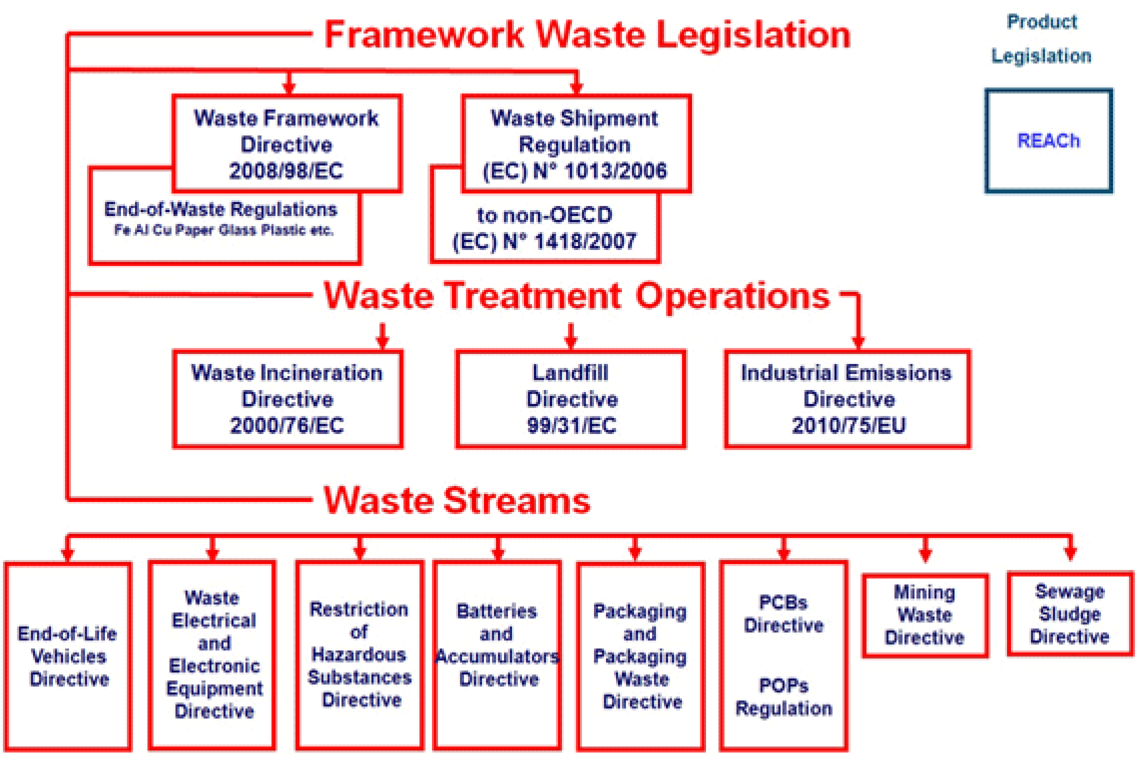


Figure 3: Waste laws (Eurometrec, 2015)

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Sustainable growth is an important part of the Europe 2020 growth strategy to become a 'smart, sustainable and inclusive economy', with the aim to lower greenhouse gas emissions by 20% (or even 30% if the conditions are right) compared to levels of 1990, to generate 20% of its energy from renewable sources and to increase energy efficiency by 20% (European Commission, 2010b). These measures could bring net savings to EU Member States, while increasing resource productivity by 30% by 2030, enhancing GDP by nearly 1% and creating 2 million additional jobs while also reducing EU carbon emissions by 450 million tonnes by 2030 (European Commission, 2016a). The framework of measures for the promotion of energy efficiency is set out by Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency addressing the achievement of the 20% target on energy efficiency in 2020.

In addition to those, the 2030 climate and energy framework covers EU-wide targets and policy objectives for the period 2021 to 2030, with the main targets being: at least 40% cuts in greenhouse gas (GHG) emissions (from 1990 levels), at least 32% share for renewable energy and at least 32.5% improvement in energy efficiency (European Commission, 2019). Moreover the 2050 EU long-term strategy stresses the opportunities that a climate neutral Europe may bring as well as challenges that may appear, without revising the 2030 targets nor launching new policies (European Commission, 2018). Overall this strategy is meant to provide a framework for the EU to achieve the Paris Agreement objectives and tackle climate change by limiting global warming to below 2°C and attempting to limit it to 1.5°C (European Commission, 2018).

Despite those regulations, not all Member States have to date implemented waste prevention as part of their environmental policies and hence implemented the regulations set out by WFD (FhG-IBP, 2014). Countries in Central and Northern Europe perform above average but have problems in decoupling waste production from growing consumption; average performing countries are mainly located in Southern and Central to Eastern Europe, whereas these have deficits in collection coverage and in the planning of future treatment capacity (FhG-IBP, 2014). The largest implementation gaps can be found in member states in Southern and Eastern Europe in all key elements for good waste management systems (FhG-IBP, 2014). These performances can be seen also in Figure 4.

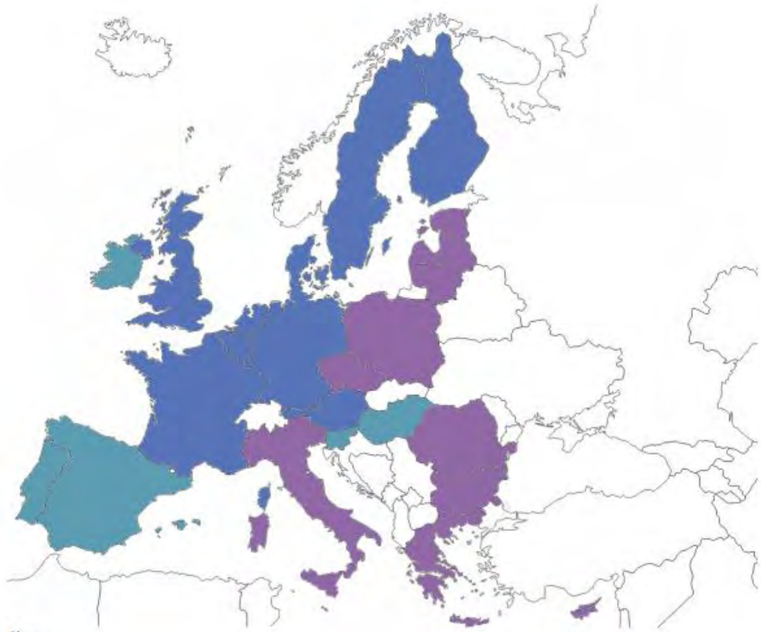


Figure 4: Waste management performance across Europe (FhG-IBP, 2014)

The regulations and Directives presented above are the ones that formulate the legislative background in Europe. Over the last years (2014 onwards) the EU has proposed some measures to enhance Europe's transition to a more circular economy, thus creating a new policy background (European Commission, 2016a). By providing greater resource efficiency and ultimately turning waste into a resource, this approach entails benefits for competitiveness, growth and employment, as well as the environment in whole (European Commission, 2016a). Moreover and based on these regulations, waste prevention programmes are running in European countries to tackle the issue of effective waste management. Figure 5 presents the status and duration of 36 waste prevention programmes in Europe by 1 December 2015. As expected the status of implementation differs widely among European countries of the North and South.

Waste prevention policy solutions are more difficult to be put in practice, because the change is differently perceived and because interventions are usually on a global scale; non-pricing options, such as product standards, information policies and voluntary agreements will most probably not deliver efficient consumption and production decisions by themselves (Defra, 2011a).

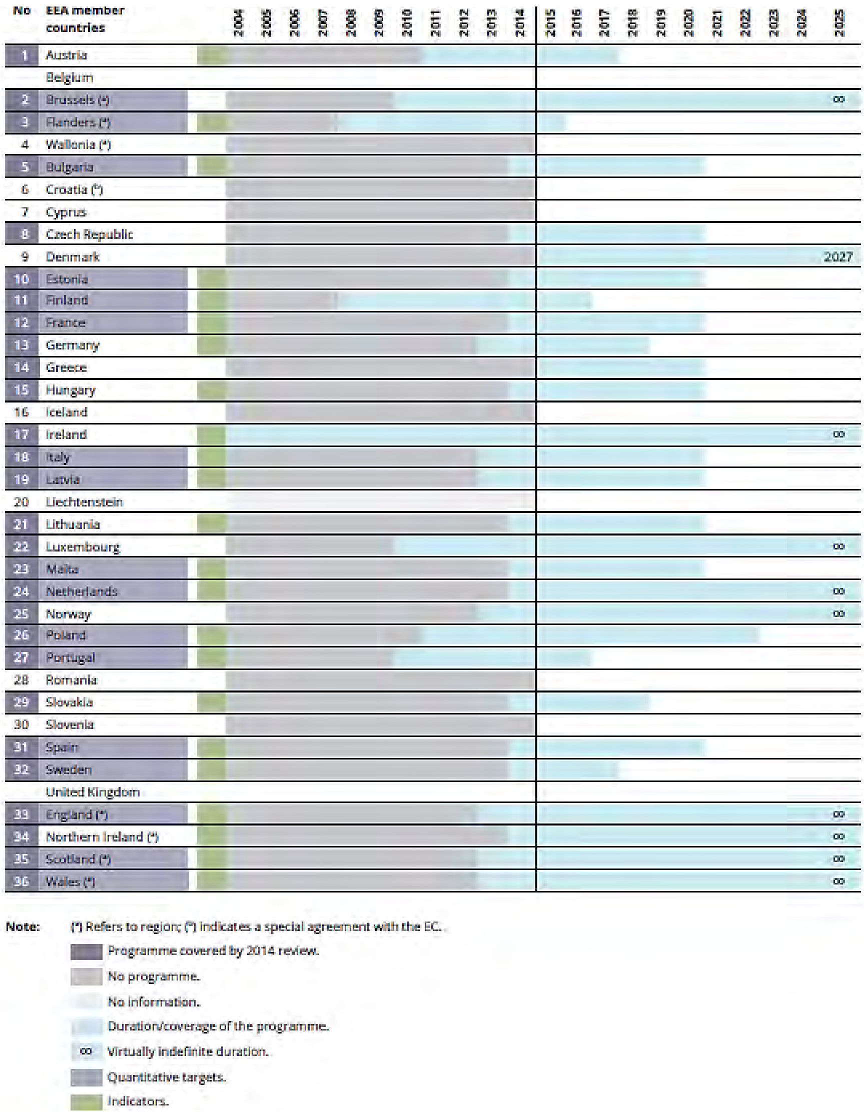


Figure 5: Status and duration of 36 European waste prevention programmes (European Environment Agency, 2015a)

To that end and to enhance these approaches, the European Commission has adopted an ambitious Circular Economy Package, with aims to accelerate Europe's transition towards a circular economy by certain legislative proposals (European Commission, 2016a). To make sure this plan is implemented effectively, along with the waste reduction targets there are concrete measures to overcome obstacles on the ground and smooth the different situations across EU Member States

(European Commission, 2016a). The main elements of the revised waste proposal include (European Commission, 2016a):

- A common EU target to recycle 65% of MSW by 2030 and 75% of packaging waste by 2030.
- A compulsory landfill target to reduce landfill to maximum of 10% of all waste by 2030.
- A ban on landfilling of separately collected waste.
- Promotion of economic instruments to avoid landfilling .
- Better established definitions and similar calculation methods for recycling rates throughout the EU.
- Stringent measures to promote re-use and stimulate industrial symbiosis (turning one industry's by-product into another industry's raw material).
- Economic incentives for producers to support recovery and recycling schemes (e.g. for packaging, batteries, electric and electronic equipment, vehicles).

As mentioned the new proposals come along a review of the EU's current waste targets and stress that waste policy has been and should continue to be a powerful driver for recycling and re-use, but there is more work to be done before being able to close the loop, as presented in Figure 6 (European Commission, 2016b). The elements provide a holistic framework, including all the steps from raw materials, design, production, distribution, consumption, collection and recycling – back to the reuse of materials.

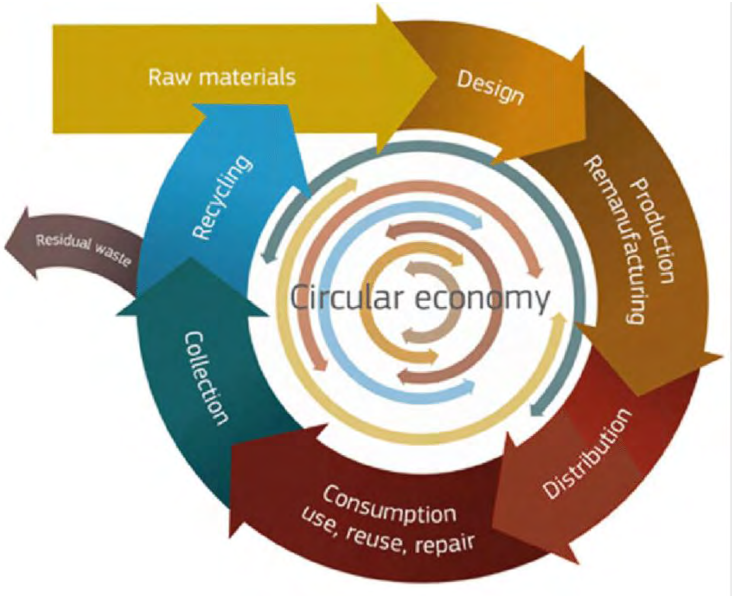


Figure 6: EU Circular Economy – Closing the loop (European Commission, 2016b)

All these measures mentioned above, could bring net savings to EU businesses of up to €600 billion, while also reducing greenhouse gas emissions. These along with further measures to increase resource productivity by 30% by 2030, could enhance GDP by nearly 1% and create 2 million additional jobs (European Commission, 2016b). In addition to this, a report by Imperial College London (ICL, 2015), stresses the business case for adopting a circular economy and it is shown that using resources in a closed loop system has the potential to contribute £29 billion (1.8%) of GDP and create 175,000 new jobs in the UK alone. The numbers are quite astonishing and therefore the circular economy demands further research all over Europe.

In those lines it is essential to establish an EU indicator to account for resource productivity which will help Member States enhance their policies and at the same time promote synergies across EU policy areas such as employment, enterprise and research; for instance resource productivity could be measured against a target which would combine raw material consumption and GDP, suggesting an improvement of 30% in this measure by 2030 (European Commission, 2016b). Overall it is very clear that coordinated action among Member States is needed to achieve the Circular Economy in the EU and the associated targets.

2.2 MSW arisings and composition

Finding data on waste management and waste treatment has shown to be a challenge in the past years, as the available data is diverse and sometimes (most often) outdated. It is important to have accurate data of municipal solid waste generation amount in order to be able to effectively plan a waste management system (Sukholthaman et al., 2017; Pongrácz, 2009). In order to be able to plan and assess waste and its management it is important to have accurate and reliable data on waste (Edjabou et al., 2015). So far there are no international standards for solid waste characterisation, which has led to various sampling and sorting approaches that in turn make comparisons of results from different studies challenging (Dahlén and Lagerkvist, 2008).

One way to overcome this obstacle and manage to ensure uniform coverage of the geographical area under study, is stratification sampling, which involves dividing the study area into non-overlapping sub-areas with similar characteristics (Dahlén and Lagerkvist, 2008; Sharma and McBean, 2007; European Commission, 2004). Thus far the inconsistencies in the definitions provided, may cause confusion and limit comparability of waste composition data between studies (Dahlén and Lagerkvist, 2008). According to a United Nations Environment Programme (UNEP) report (2015) some of the major areas of concern are:

- Lack of standard definitions and classifications – definitions used so far for the different waste streams vary widely among countries, even within the EU.
- Absence of measurement and of standard methodologies for measurement - thus activities outside of that system, including uncontrolled (and often illegal) dumping or burning are not accounted for. Data on waste composition are unclear and uncertain, even in high-income countries, as measurement tends to be irregular and carried out without a consistent basis.
- Lack of standard reporting systems - statutory reporting systems for waste management in a standard format still are not the case. National data collection systems usually do exist for MSW but this is not the case for other waste streams such Commercial and Industrial (C&I) and Construction and Demolition (C&D). Although there are some coherent data from Eurostat and the Organisation for Economic Co-operation and Development (OECD), there are many gaps which hinder comparability between different countries. Double counting is also very common, as in many cases when waste is processed, the output from the treatment facility is counted again as 'new' waste.

Based on the information presented above, it comes to reason that waste composition differs not only across countries, but also by region according to but not limited to the following factors (Eunomia, 2015; Yamaguchi and Managi, 2017; UNESCO/UNU-IHDP and UNEP, 2014): socioeconomic status, consumption habits, season, whether or not households have gardens and presence (or not) of tourists. There is also a connection between buying capacity of the population in urban centres and amount of MSW generated (Ojeda-Benitez et al., 2003). From a recent study conducted in Denmark it was found that the waste composition from single-family and multi-family houses were different showing that differences in housing types cannot be ignored either (Edjabou et al., 2015). Moreover the statistics depend on the methodology that is employed and should account for other factors related to waste as well for instance the physical characteristics of waste such as moisture (Eunomia, 2015).

The Waste Atlas Partnership has evaluated the world's 50 biggest active dumpsites (Figure 7) most of which are located in Africa, Asia and Latin America/Caribbean and two in Europe (UNEP, 2015). These differ in size, in the waste they handle and accommodate different numbers of people either working at the dumps or living in the surroundings; however these 50 sites all have in common that they are dangerous to human health and the environment (UNEP, 2015).

A close interrelationship between waste quantity/quality and socio-economic status of households in developing countries have not been proven by many researchers thus far (Qu et al., 2009; Sujauddin et al., 2008; Thanh et al., 2010).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Figure 7: World's 50 biggest dumpsites (UNEP, 2015)

In all parts of the world, an increase in income can affect the consumption patterns of households and therefore the composition and quantity of MSW (Ogwueleka, 2013). At the same time and as shown in Figure 8 there is also a strong relationship between waste per capita and income levels per capita; namely there is a strong positive correlation, with the average generation in high-income countries being about six-fold greater than in low income countries (UNEP, 2015). At the same time, there is also considerable variation within countries.

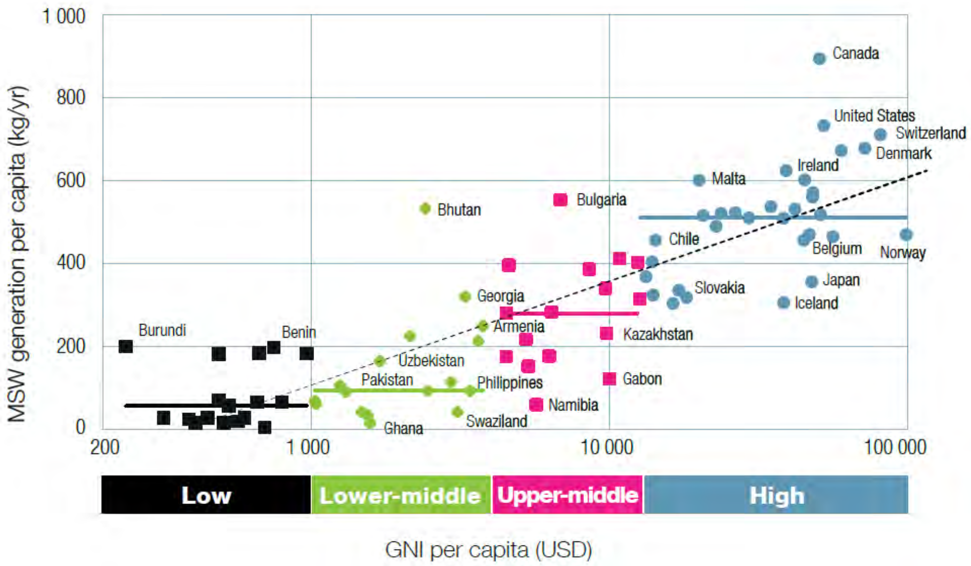


Figure 8: Waste generation versus gross national income (GNI) level by country for 82 countries (UNEP, 2015)

As already mentioned MSW consists of everyday items we use and throw away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries – it originates from homes, schools, hospitals, and businesses (EPA, 2015). The definition of municipal waste varies across countries; however, for most countries MSW includes waste collected by local authorities in the form of household waste) as well as commercial waste and also waste originating from maintenance of public areas (Eunomia, 2015).

In urban cities of developing countries, management of MSW is highly neglected (Zhen-shan et al., 2009; Batool and Ch, 2009; Chung and Lo, 2008; Imam et al., 2008; Berkun et al., 2005; Metin et al., 2003; Ahmeda and Alib, 2004) and there is limited space for further development because government budgets are limited and more than often collection is disregarded (McBean et al., 2005). The main issue is not the absence of environmental legislation, but rather the lack of enforcement and/ or the availability of viable alternatives in place (Fourie, 2006). At the same time, there is also considerable variation within countries themselves. There are also some other concepts around waste which need to be further defined. For instance biodegradable waste includes waste capable of being decomposed by the action of biological processes. This category is often neglected and includes garden, kitchen and food waste accounting for about 1/3 of the waste that is thrown away at home –

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

translating to around 88 million tonnes across Europe each year (European Commission, 2010b). The amount of MSW should be rather well known today as Member States in the EU are required to provide this information under the Waste Framework Directive (Eunomia, 2015). Figure 9 presents the MSW generated per Member State in 2003 and 2013 sorted by 2013 waste per capita. Generation of municipal waste per capita has declined slightly over the years with better management techniques in place as well, whereas the number of countries recycling and composting increased from 11 to 17 out of 35, and those landfilling more than 75% of their municipal waste declined from 11 to 8 (European Environment Agency, 2015a).

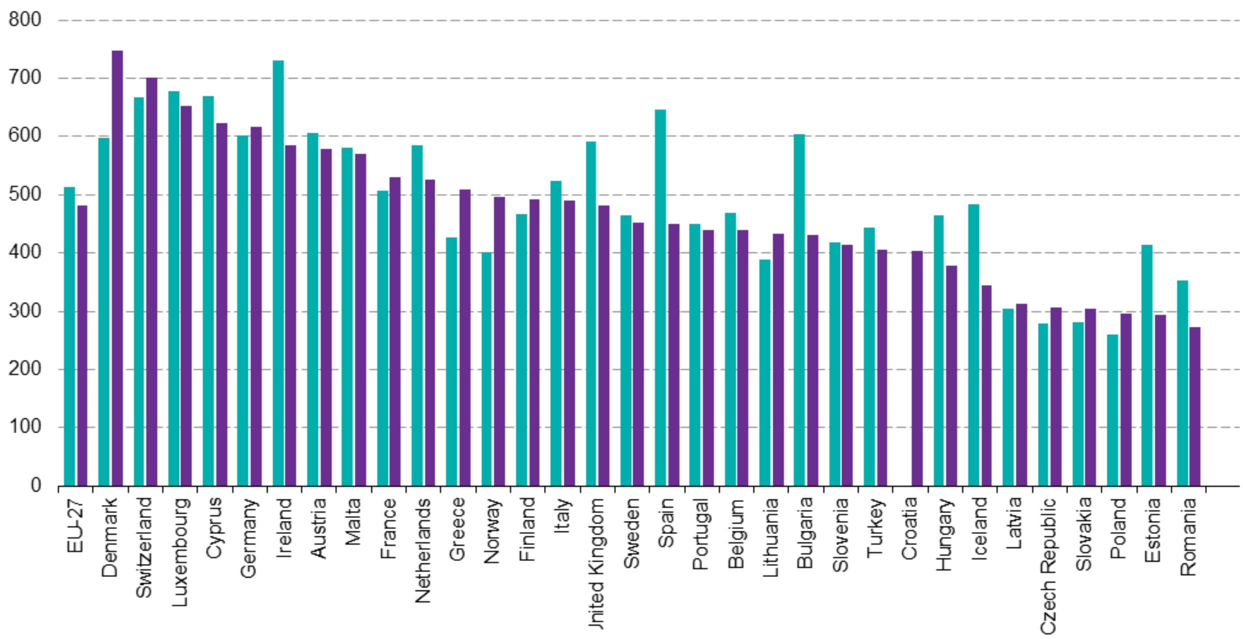


Figure 9: Municipal waste generated by country in 2003 and 2013, sorted by 2013 level (kg per capita) (Eurostat data) (blue: 2003 and purple: 2013)

Apart from the exact amount of waste produced in a country, understanding the composition of waste is also important which in most cases is not straightforward, because waste composition is very different across the world (Eunomia, 2015). Moreover in Figure 10 the aggregated data on the amount of waste fractions (tonnes per annum - t/a) for EU Member States and associated countries are shown, presenting the varying composition of waste among EU countries.

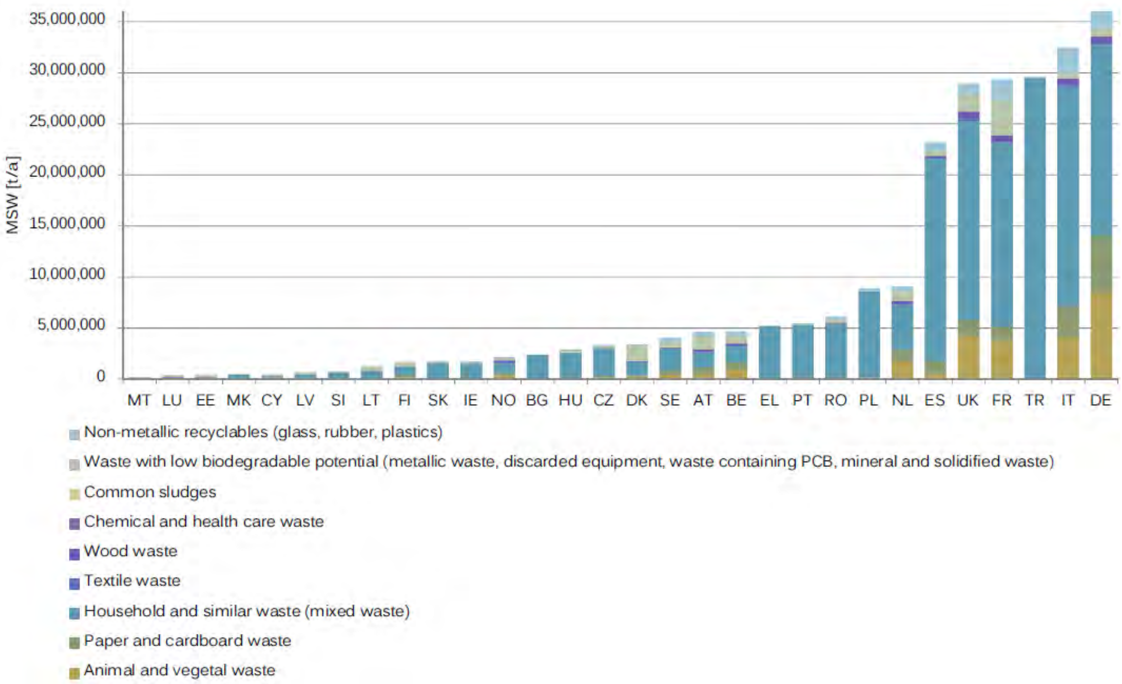


Figure 10: Aggregated data on amount of MSW (t/a) in EU Member States (2010 Data) (FhG-IBP, 2014)

In relation to Figure 8, Figure 11 presents the variation of MSW composition grouped by country income levels from data on 97 countries. Organic material takes most space in all income levels, but obvious differences can be noticed among different income levels which are associated with the living conditions and lifestyle of the people there.

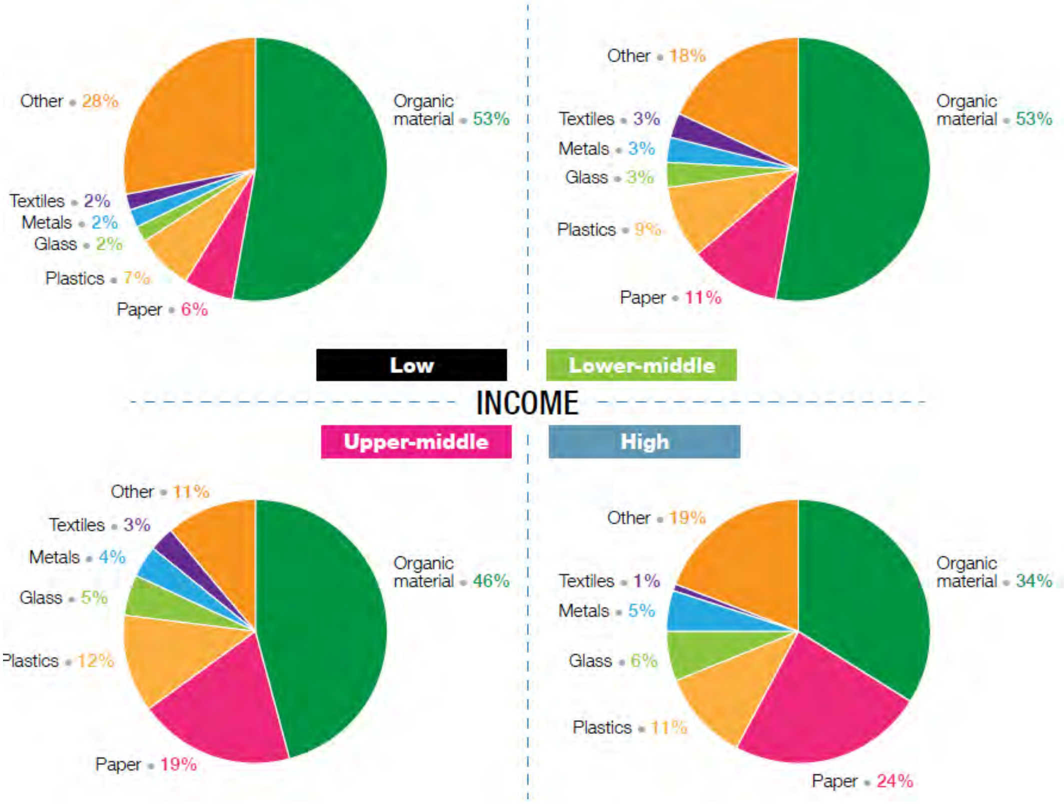


Figure 11:Variation in MSW composition (%) grouped by country income levels (UNEP, 2015)

At the same time, Figure 12 presents a comparison between 2010 and 2020 waste arisings. The amount of MSW calculated has been allocated equally between all countries, provided that the requirements of the Landfill Directive were fulfilled (green bar) and the data for 2020 arisings (yellow bar) have been extrapolated on data basis of 2004, 2006 and 2008 (Eunomia, 2015).

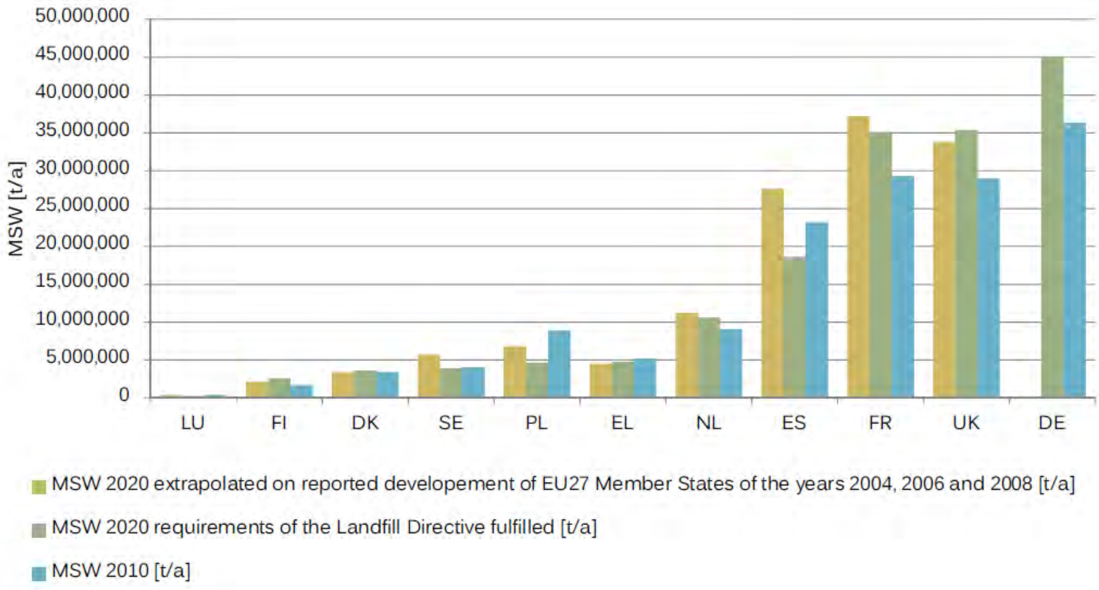


Figure 12: Generation of MSW in 2020 compared with data of 2010 (Eunomia, 2015)

As has been presented already, there are waste prevention programmes already in practice all over Europe. At the same time it is useful to have a clear picture of the waste prevention programmes by sector and not just by country, as presented in Figure 13.

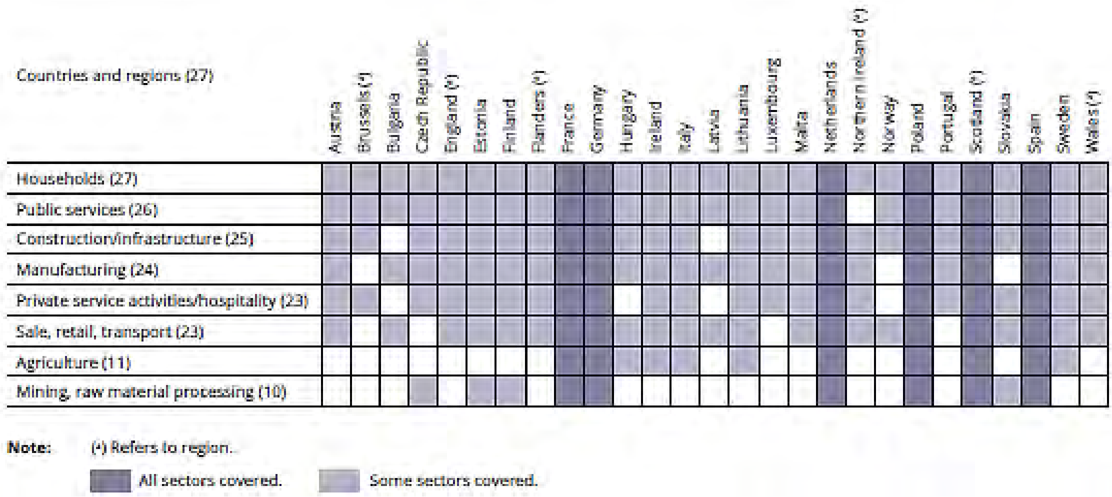


Figure 13: Waste prevention programmes by sector (European Environment Agency, 2015a)

It is important to note that waste prevention does not only take place during collection but it starts even from production and under a life-cycle thinking approach includes preventative steps during production (including production and transport), consumption and collection. These in summary can be seen schematically in Figure 14.

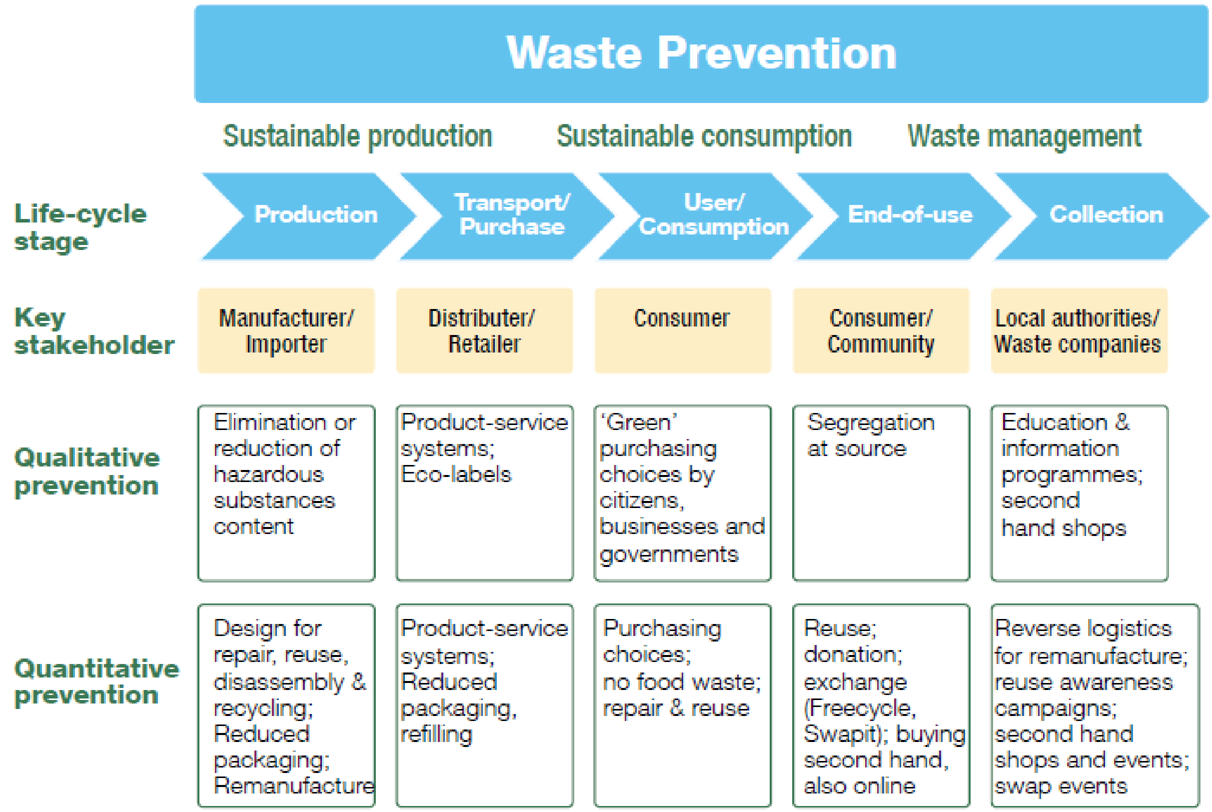


Figure 14: Waste prevention at different stages in product life-cycle (UNEP, 2015)

Sustainable consumption and production (SCP) thinking has gained a lot of attention recently and one important pillar of this, is waste prevention as at the same time awareness is increasing that our society is reaching the limits of a finite planet in terms of resources and resource use (UNEP, 2015). These waste prevention programmes need to be more stringent and put in place as waste arisings are projected to further increase by 2100 as shown in Figure 15.

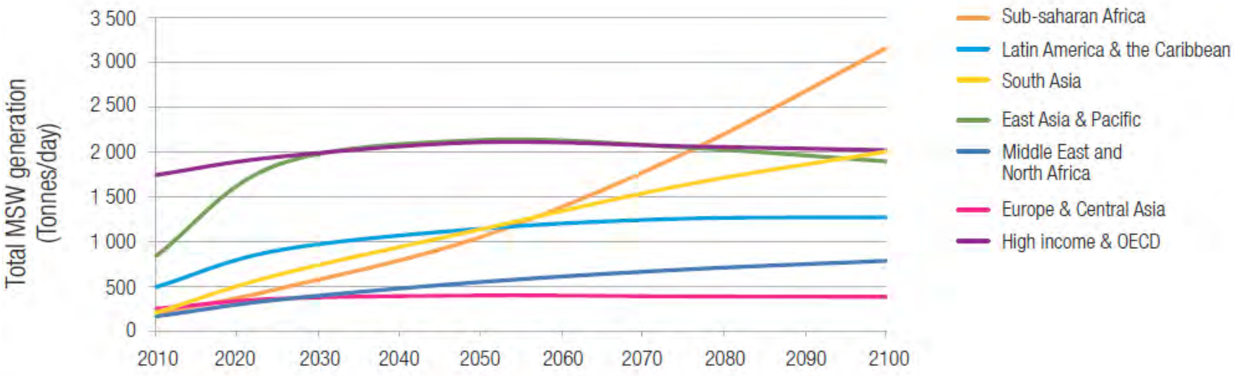


Figure 15: Projection of MSW generation in 2100 by world region (UNEP, 2015)

2.3 Waste infrastructure and treatment options for MSW

Despite these regulations, the countries within the EU employ different treatment options in their areas with some already moving towards materials recovery systems while for others this is still a virgin territory (Eunomia, 2015). Based on the Waste Hierarchy, Table 1 includes a short description the options that are available from most preferred to least preferred. A well-planned waste management system includes all activities that aim to minimize the health, environmental and aesthetic impacts of MSW (Suthar and Singh, 2015; Kungolos, 2016); as the uncontrolled waste disposal can pose serious threats to urban surface water resources and significant environmental health risks to those living in the vicinity (Bhuiyan, 2010).

Table 1: Waste hierarchy options explained (Adapted from European Commission, 2010b)

Prevention
Preventing waste being produced in the first place is essential. One of the key tools being used to encourage waste prevention is eco-design, focusoing on environmental aspects during the conception and design phase of a product.
Re-use
Re-use inlcudes the repeated use of products and/or components for the same purpose for which they were produced originally (i.e. refrigerators, ink cartridges and computer printers).
Recycling
Recycling provides EU industries with essential supplies recovered from waste such as paper, glass, plastic and metals, as well as precious metals from used electronic devices. These systems include Extended Producer Responsibility, which

makes producers responsible for the entire life cycle of the products and packaging they produce, including the last stage of the product life cycle, when it becomes waste. Individuals also play a crucial role, as in many cases they are asked to separate their waste into different material types (paper, glass, plastics, metal, garden waste and so on).
Energy recovery
Waste incineration plants can be used to produce electricity, steam and heating for buildings. Waste can also be used as fuel in certain industrial processes.
Landfill
Landfill is the least desirable option because of the many potential adverse impacts it can have, such as the production and release into the air of methane, a powerful greenhouse gas 25 times stronger than carbon dioxide. In addition to methane, the breakdown of biodegradable waste in landfill sites can release chemicals such as heavy metals resulting in run-off called leachate. This liquid can contaminate local groundwater and surface water and soil, which could pose a risk to public health and the environment. Alternative actions to get benefits from landfills include: - The methane produced by an average municipal landfill site, if converted to energy, could provide electricity to approximately 20,000 households for a year. - It is estimated that the materials sent to landfill could have an annual commercial value of around €5.25 billion.

The following flowchart (Figure 16) presents the most common municipal waste treatment operations which are broken down into these categories (European Commission, 2012a): mechanical biological treatment (MBT), incineration, recycling, composting and landfilling.

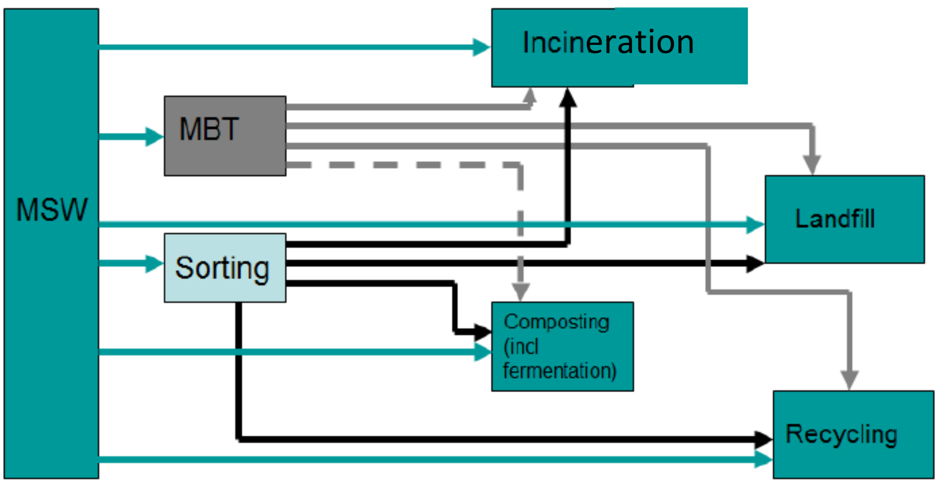


Figure 16: Municipal waste treatment options (European Commission, 2012a)

All these treatment options are used in every country and to a different extent. Furthermore the following sections present the main points around the most used waste management treatment options used worldwide and in the EU.

2.3.1 Mechanical Biological Treatment

MBT is a process designed to optimise the use of resources by recovering materials for one or more purposes and stabilising the organic fraction of residual waste (Eunomia, 2015). Through MBT the so-called Refuse Derived Fuel (RDF) or Solid Recovered Fuel (SRF) can be produced. RDF generally includes sewage sludge, waste wood, calorific fractions of household and commercial waste, shredder lightweight fractions, scrap tyres, food byproducts (Sarc and Lorber, 2013). MBT is a residual waste treatment process that involves both mechanical and biological treatment (Defra, 2013a).

Some of the benefits of MBT include the fact that materials and energy can be recovered, space requirements are reduced and gas and leachate emissions from landfill are reduced at the same time (Eunomia, 2015). MBT systems basically comprise two simple ideas: either to separate the waste and then treat or to treat the waste and then separate (Defra, 2013a). Aerobic biological unit processes are used to 'stabilise' the organic fraction, to reduce its biodegradability and therefore its ability to generate methane, whereas anaerobic biological unit processes can help produce biogas from the organic portion of MSW (UNEP, 2015).

In those regards RDF must fulfill general quality requirements in order to be safely and efficiently used such as (Sarc and Lorber, 2013):

- well defined calorific value,
- low chlorine content
- quality controlled composition (few impurities)
- defined grain size
- defined bulk density
- availability of sufficient quantities with required specifications.

Figure 17 presents a schematic representation of the MBT inputs and outputs.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

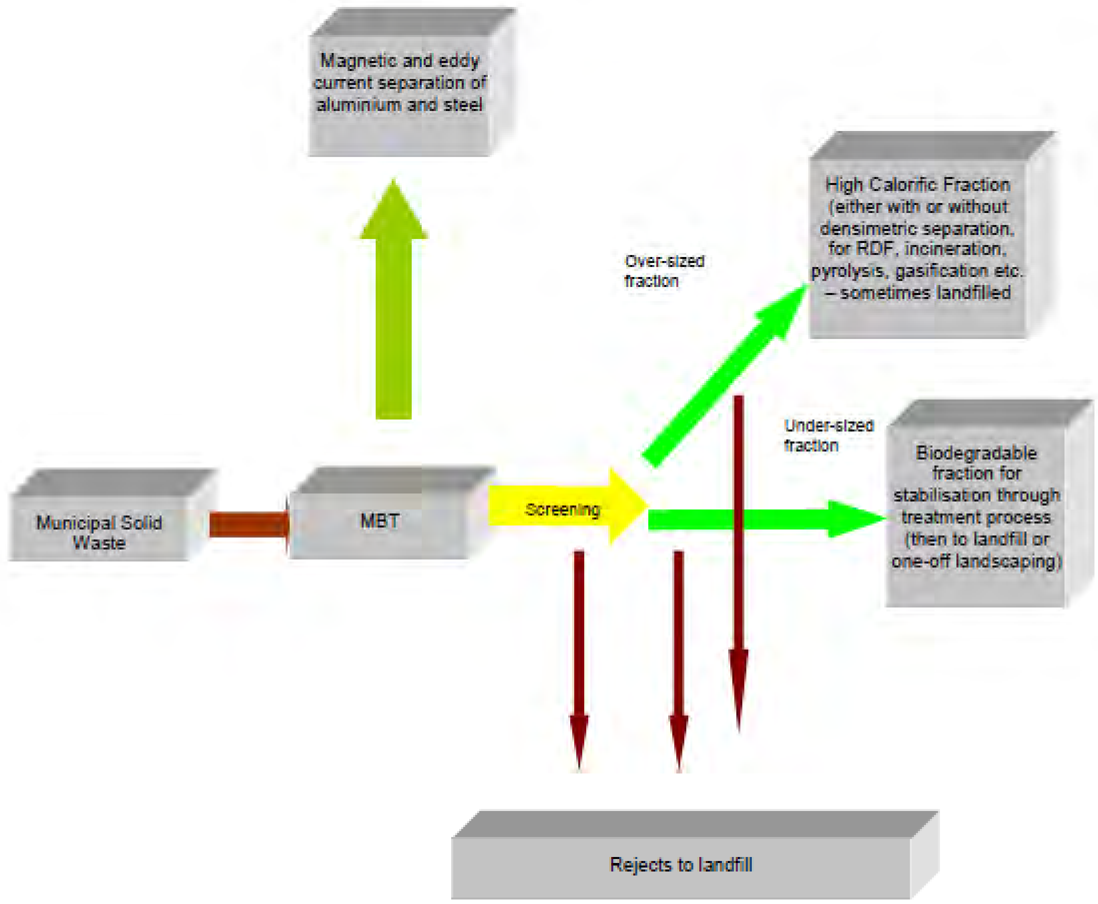


Figure 17: Schematic representation of MBT inputs and outputs (Eunomia, 2015)

The main outlets for outputs from MBT systems for MSW include (Defra, 2013a):

- Materials recycling: recyclables from the various MBT processes are typically of a lower quality and therefore have a lower potential for high value markets, but generally contribute to enhancing the overall recycling levels.
- Use of Compost-like output (CLO): the processing of mechanically separated organics can produce CLO or digestate material.
- Production of biogas: an MBT plant with Anaerobic Digestion (AD) as its biological process will be able to produce biogas.

- Materials recovered for Energy: where the MSW is sorted to produce a high calorific value waste stream for instance including mixed paper, plastics and card, this stream may be known as Refuse Derived Fuel (RDF).

2.3.2 Incineration

The combustion of waste for recovering energy, is called incineration, where under conditions of high temperature these waste treatments are recognised as thermal treatments (WMR, 2009). Eunomia (2015) report provides a detailed analysis of how incinerators work as presented below in short: 'in mass burn incinerators, waste is first fed into a feed chute where a ram pushes the waste on to the first section of the incinerator grate, which includes a series of rocking sections, rotating rollers or alternate fixed and moving sections. At every step there is presence of oxygen at very high temperatures. The carbonaceous/hydrogenous waste is dried and oxidised (combusted) with air supplied through the grate. Energy recovery can be obtained by the combustion gases transferring their heat to refractory-lined water tube sections and convective heat exchangers both of which feed the boiler. Steam from the boiler can be used for district heating or in a turbine for power production to an electricity grid.'

Incineration reduces the form of the waste from 95 to 96% and this reduction depends on the recovery degree and composition of materials; this means that incineration does not replace the need for landfilling but reduces the amount to be disposed that way (WMR, 2009). Figure 18 presents the main outputs and inputs from Incineration.

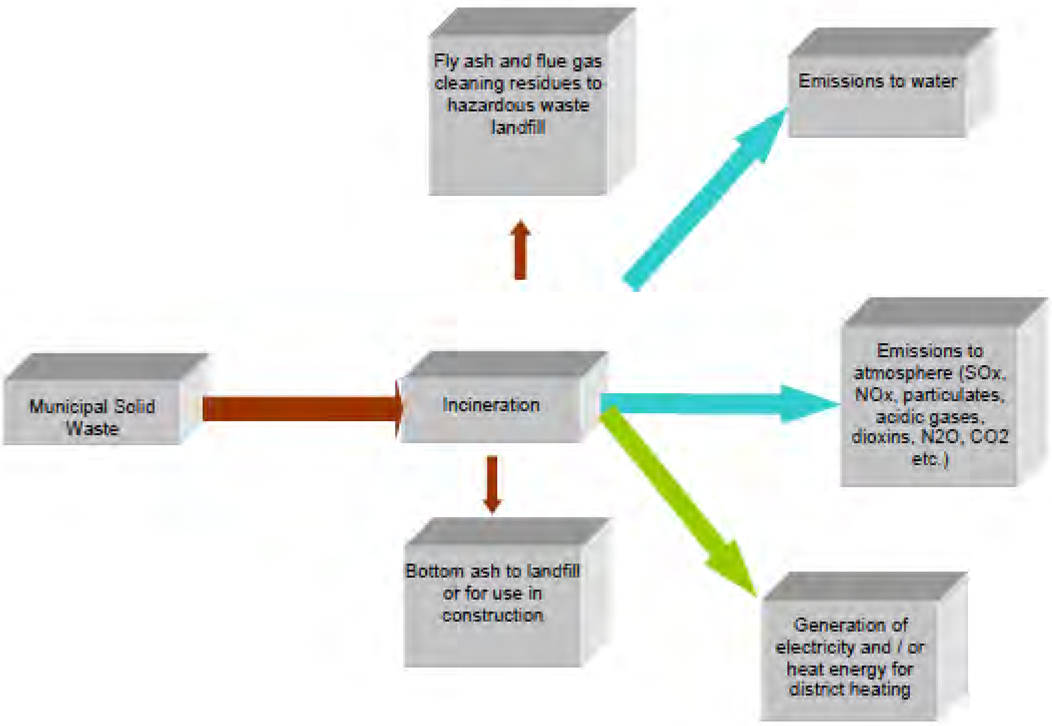


Figure 18: Schematic Representation of Incineration Inputs and Outputs (Eunomia, 2015)

The table below summarises the key outputs from incineration processes (Table 2).

Table 2: Main output of incineration (Adapted from Defra, 2013b)

Outputs	State	Quantity by weight of original waste	Comment
Incinerator Bottom Ash (IBA)	Solid residue	20-30%	Potential use as aggregate replacement or non-biodegradable, non-hazardous waste for disposal
Metals (ferrous and non-ferrous)	Requires separation from MSW or IBA	2-5%	Sold for re-smelting

Air Pollution Control (APC) residues (including fly ash, reagents and waste water)	Solid residue / liquid	2-6%	Hazardous waste for disposal
Emissions to atmosphere	Gaseous	Represents 70-75%	Cleaned combustion products

In 2009 there were 449 Incineration plants operating across 20 Western and Central European countries with a total throughput of around 69.4 million tonnes of waste for 2009 (Defra, 2013b). In 2016 there were 512 plants in Europe alone providing a total incineration capacity of 93 million tonnes (Scarlat et al., 2018). In many countries such as Germany and Japan, incinerators are widely used to treat both MSW and industrial waste (Chen et al., 2010). Incineration is a quite controversial technology and opinions are separated as to where and if it should be used. Generally public disagreement can affect political willingness to support incineration, which has been the case especially for Spain and Greece (de Beer et al., 2017). WMR (2009) provides a summary of the main points against and in favour of incineration. Specifically some of the arguments supporting incineration are:

Arguments supporting incineration:

- Despite concerns on the health effects of incineration processes, emission can be controlled by developing modern plants and more stingent regulations.
- Incineration plants can produce energy and thus substitute other power generation plants.
- The bottom ash is considered non-injurious and still capable of being landfilled and recycled.
- Fine particles are removable through filters and scrubbers.
- Finally teating and processing of medical and sewage waste produces non-injurious ash as end product.

Arguments against incineration:

- Many consider the products of incinerations as extremely injurious matter which require adequate disposing of, meaning additional miles and special locations for landfilling this.
- There are still many concerns about the emission of furans and dioxins.
- Incinerating plants are producers of heavy metals, which are injurious even in minute quantities.

GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

- Initial investment costs are only recovered under longterm contracts.
- Local communities always have and probably will be opposed to the presence of incinerating plant in their vicinity.
- The supported view is to recycle, reuse and reduce waste instead of using incineration.

At the same time likewise relatively new technologies include pyrolysis and gasification but these still remain fairly unproven in European usage (Eunomia, 2015).

Pyrolysis is the thermal decomposition of materials in the absence of oxygen (Bridgwater, 2012). The pyrolysis of biomass results in the production of char, liquid and gaseous products (Figure 19) (Maschio et al., 1992). It can be divided into three main parts: conventional pyrolysis, fast pyrolysis and flash pyrolysis (Derimbas and Arin, 2002). More recently research has focused on fast pyrolysis in which case waste is decomposed quickly under high temperatures and produces bio-oil. The main features of a fast pyrolysis process are (Bridgwater and Peacocke, 2000):

- very high heating and heat transfer rates
- carefully controlled temperature of around 500°C
- rapid cooling of the pyrolysis vapours.

Bio-oil that is produced through pyrolysis can substitute fuel oil or diesel for instance in boilers, furnaces, engines and turbines for electricity (Bridgwater, 2012). Even though the production of crude bio-oils has been researched extensively, little progress has been made to produce additives or transportation fuel extenders from these oils, therefore this is an area that has to be further examined (Garcia-Perez et al., 2010).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

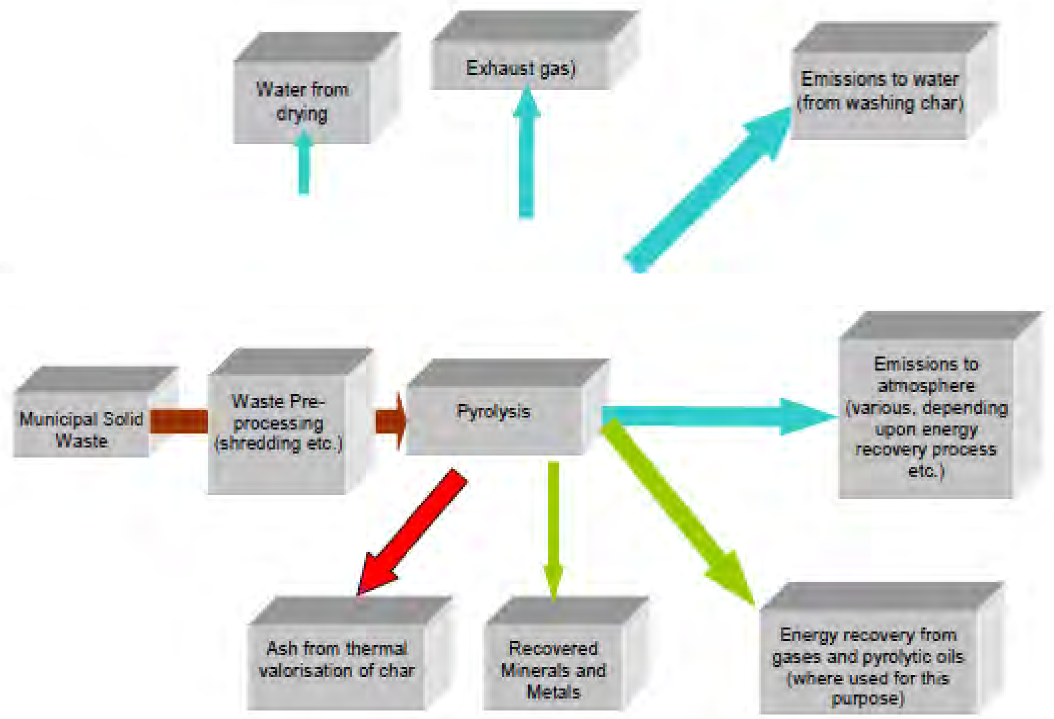


Figure 19: Schematic representation of single pyrolysis process inputs and outputs (Eunomia, 2015)

Gasification is considered as a process between pyrolysis and combustion because it entails the partial oxidation of a substance (Defra, 2013b). It involves heating carbon rich waste in almost anaerobic conditions, whereas the majority of carbon is converted to a gaseous material leaving an inert residue from the breakdown of organic molecules (Eunomia, 2015). In gasification (Figure 20) carbon based wastes are heated in the absence of oxygen to produce a solid, low in carbon and energy from syngas which is a fuel gas mixture consisting of hydrogen and carbon monoxide (Defra, 2013b), and can therefore be considered as a thermochemical process. Gasification is highly efficient and has low environmental emission rates therefore it is a quite desirable technology (Higman, 2008). It is a viable alternative to incineration specifically for thermal treatment of homogeneous carbon-based waste and for pre-treated heterogeneous waste (Belgiorno et al., 2003).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

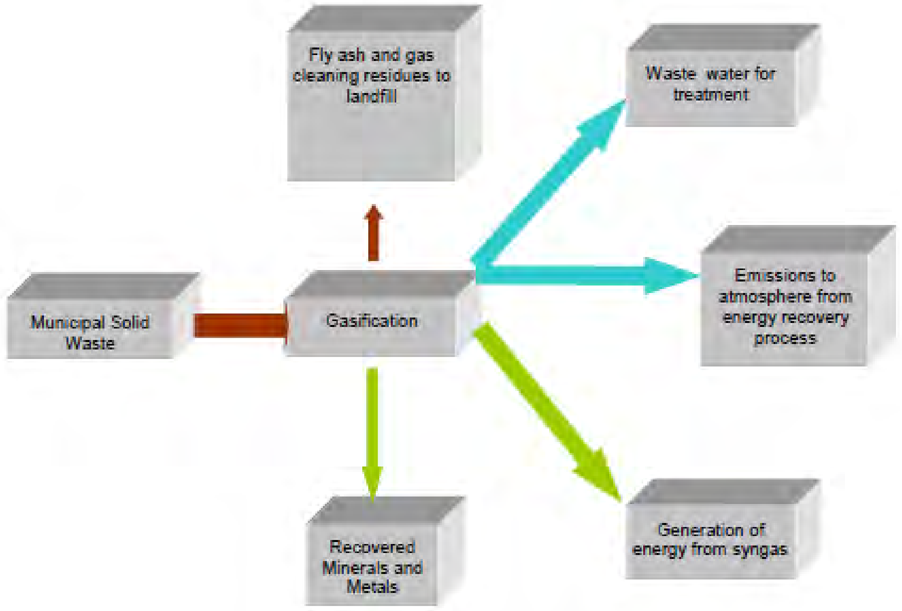


Figure 20: Schematic representation of gasification inputs and outputs (Eunomia, 2015)

Incineration, pyrolysis and gasification are all considered thermal treatment but differ in the levels of air used in those as shown in figure 21.

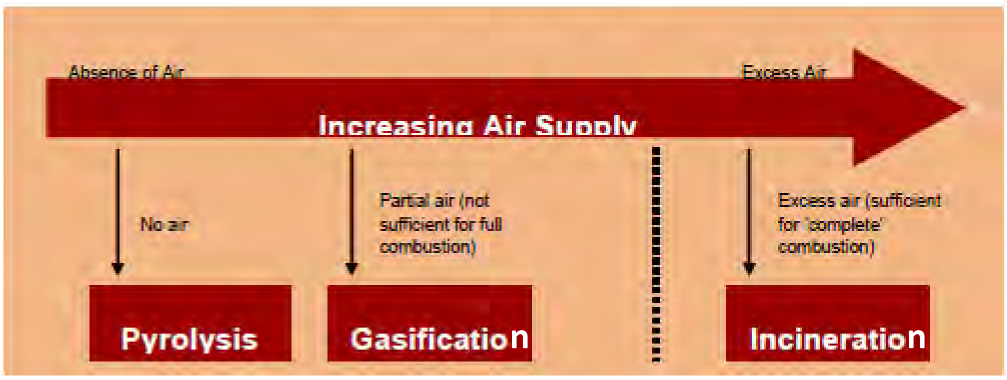


Figure 21: Levels of air (oxygen) present during pyrolysis, gasification and incineration for MSW (Defra, 2013b)

2.3.3 Composting

Composting is a term used to describe the biodegredation of organic matter through an aerobic process which converts organic matter into a stable humic substance (Eunomia, 2015). In most developing countries an astonishing 50 to 70% of the MSW is organic materials which are therefore suitable for composting, so the process can usually be furthered through separation at source (UNEP, 2015). More specifically for this process, the microorganisms employed are part of three main categories; bacteria, fungi and actinomycetes.

The key factors that need to be accounted for to achieve effective composting rates include: temperature, air supply, moisture content, the porosity of the material and its carbon to nitrogen ratio (Eunomia, 2015). There are many different technologies available for composting which include simple open-air systems (windrow composting and aerated static pile composting) to more sophisticated contained systems (Environment Agency, 2002). Figure 22 presents a schematic representation of composting inputs and outputs.

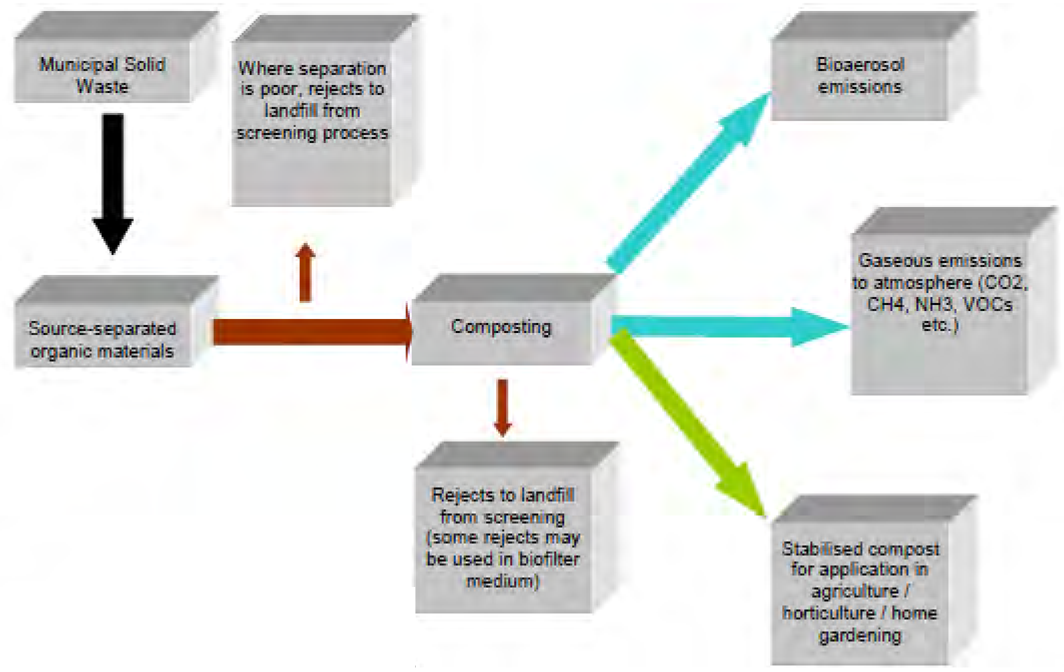


Figure 22: Schematic representation of composting inputs and outputs (Eunomia, 2015)

Composting facilities can only operate economically if they function at or near maximum design capacity. Therefore this implies that for every composting facility one needs to secure sufficient waste (Environment Agency, 2002). The quality of the compost produced depends mainly on the quality of the feedstock used to make it; as compost will only be of beneficial use, and of commercial value, if it is made to the highest quality possible with sufficient quality control. Based on their quality, waste-derived composts can be used for land reclamation and as a soil improver in landscaping, agriculture and horticulture due to its ability to improve the biological and physical properties of soil in particular of use in arid regions (Environment Agency, 2002; UNEP, 2015).

2.3.4 Anaerobic Digestion (AD)

In addition to the methods presented in Figure 16, a further treatment method is anaerobic digestion (AD) which is the bacterial decomposition of organic material in almost anaerobic conditions whose by-products include biogas, and digestate (Eunomia, 2015). There are two main types of anaerobic digestion called thermophilic and mesophilic – the primary difference between them is the temperatures used in the process; thermophilic processes reach temperatures of up to 60^{o} C and mesophilic normally run at about 35-40^{o} C (WRAP, 2016).

The high degree of flexibility associated with AD is considered one of the most important advantages of the method, since it can treat several types of waste, ranging from wet to dry and from clean organics to grey waste (Eunomia, 2015). AD (Figure 23) can in comparison to composting better treat waste with a higher moisture content and can occur usually between 60% and 99% moisture content (Eunomia, 2015). Hence kitchen waste and other putrescible wastes which are high in moisture can be an excellent feedstock for AD, whereas woody wastes including a higher proportion of lignocellulosic materials are better suited to composting.

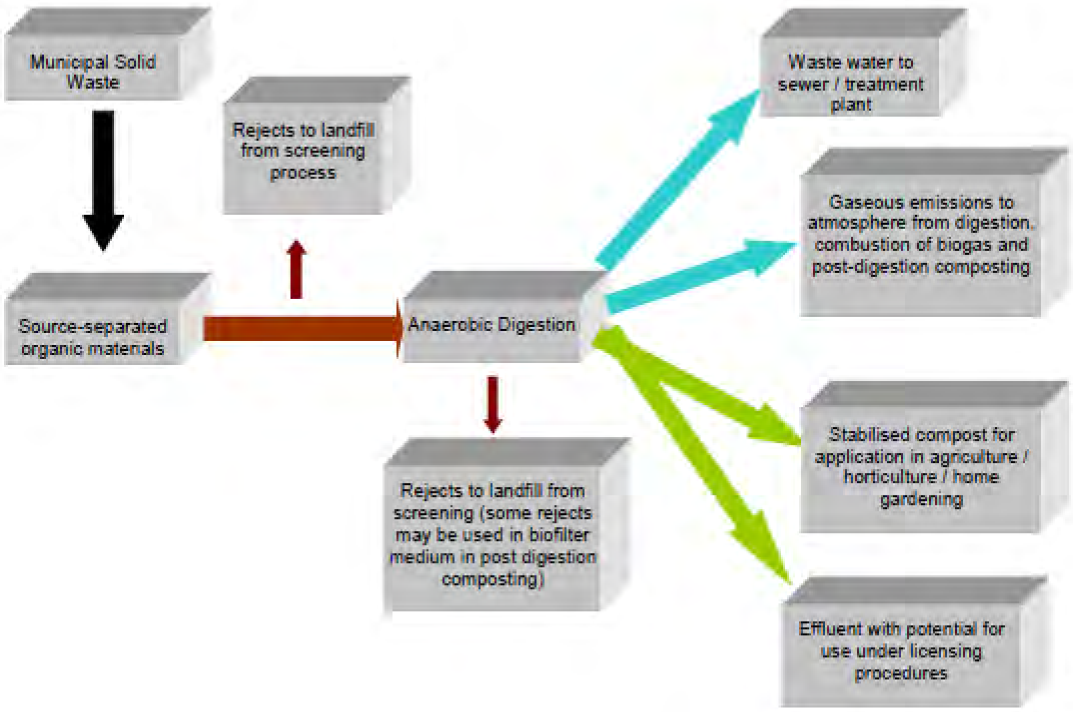


Figure 23: Schematic representation of AD inputs and outputs (Eunomia, 2015)

The process of AD provides a source of renewable energy, since the food waste is broken down to produce biogas (a mixture of methane and carbon dioxide), which can be used to produce energy. The biogas can be used threefold: to generate electricity, to power on-site equipment and any excess electricity can be exported to the National Grid. Biogas is a mixture of around 60% methane, 40% carbon dioxide and some other traces of other contaminant gases but its exact composition will depend on the type of feedstock being digested. Possible uses its potential to provide heat, electricity or both. Alternatively, the biogas can be 'upgraded' to pure methane, often called biomethane, by removing other gases. One cubic metre of biogas at 60% methane content converts to 6.7 kWh energy (Defra et al., 2016).

A further by-product of the process is the digestate, which is rich in nutrients such as nitrogen, phosphorus and other elements essential for healthy plant growth and fertile soil (WRAP, 2016). The digestate produced is usually stored until it's needed, and can be separated into liquid and solid segments. The biogas produced will be stored before being either developed further into biomethane

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

for vehicle fuel or for injection into the gas grid or burned in a combined heat and power engine to produce electricity and heat (WRAP, 2016).

Digestate is a nutrient-rich substance that can be used as a fertiliser, consisting of leftover materials and decomposed micro-organisms - the volume of digestate usually comes out to be around 90-95% of what was fed into the digester initially (Defra et al., 2016). It must be noted that digestate is not compost although it has some similar features; compost is produced by aerobic micro-organisms, meaning they require oxygen from the air (Defra et al., 2016).

2.3.5 Recycling

Recycling refers to the systematic collection, processing and reuse of materials, which include the following categories: paper, glass, plastic, wood, aluminium products and iron (Halkos, 2013a). Recycling entails many benefits which include amongst others the following (EPA, 2016):

- Reduces the amount of waste sent to landfills and incinerators
- Conserves natural resources such as timber, water, and minerals
- Prevents pollution by reducing the need to collect new raw materials
- Saves energy
- Reduces greenhouse gas emissions that contribute to global climate change
- Helps sustain the environment for future generations
- Helps create new well-paying jobs in the recycling and manufacturing industries.

Figure 24 presents the MSW recycling in 35 European countries in 2004 and 2012. It is obvious that recycling is being used more and more in recent years with high rates of development.

GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

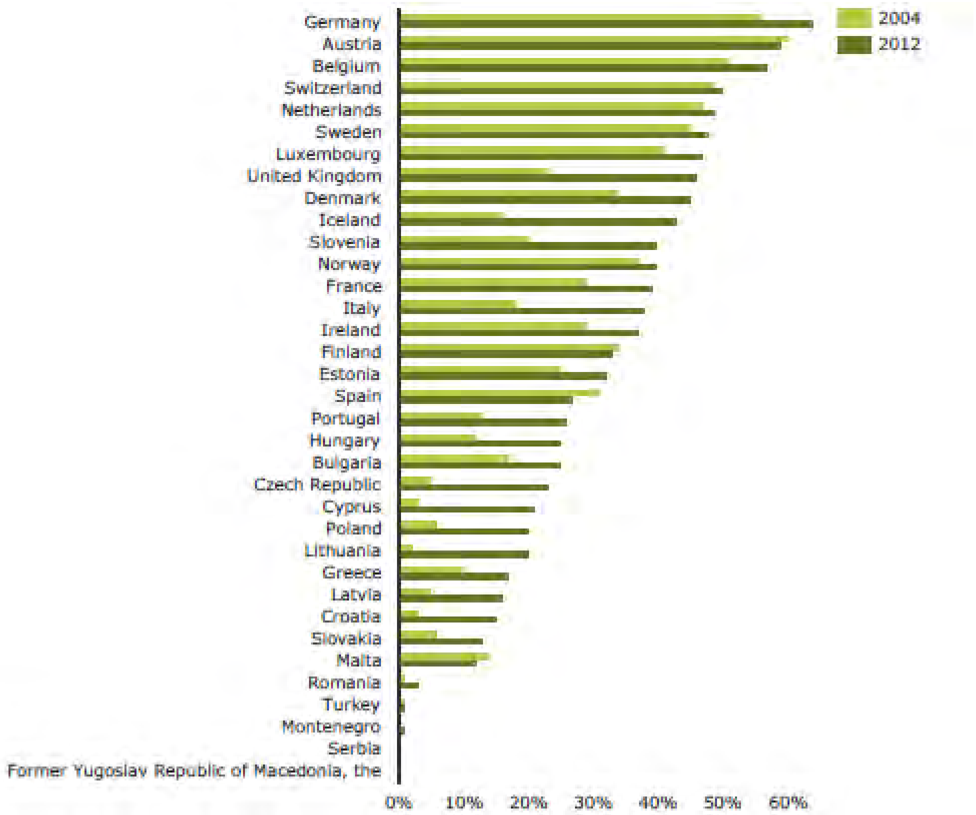


Figure 24: MSW recycling in 35 European countries (European Environment Agency, 2015b)

Also there is clearly a correlation between increasing recycling rates and declining rates of landfilling, as in countries with high MSW recycling rates, landfilling seems to be declining much faster than recycling is growing, because waste management strategies usually move from landfill towards a combination of recycling and incineration, and in some cases also MBT (European Environment Agency, 2015b).

2.3.6 Landfill

Landfilling is being considered in the past years as inappropriate because it poses great risks to human and environmental health (Kungolos et al., 2006). Still there are uncertainties as to how landfills affect human health; for instance research in the UK points out the possibility of landfills being responsible for birth defects in the vicinity (Elliott et al, 2000). A modern landfill includes a waste containment liner system to separate waste from subsurface environment, systems for the collection

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

and management of leachate and gas, and placement of a final cover after deposition is complete (Laner et al., 2012). There are two broad types of landfills:

- Traditional landfills which are uncontrolled and may allow leachate to be released into the soil and
- Modern MSW landfills which are controlled and operated using the principle of 'containment' (Eunomia, 2015), meaning that landfilled waste is separated from the environment and both leachate and landfill gas are collected and treated, including after the closure of the landfill.

Containment has been put forward, and involves operating the landfill in a condition that accelerates the decomposition processes, so that the production of leachate and landfill gas occur at the beginning and when the collection and treatment systems are in working order (Bramryd et al., 1999).

One of the main outputs of landfill is methane, which is produced through the decomposition of organic wastes under anaerobic conditions. Landfill gas which originates from the landfill operation, can be used either in a gas engine to generate electricity and/or heat, or it may be used into a natural gas grid or for direct utilisation as a transport fuel (UNEP, 2015).

Moreover a common technique to pre-treat waste before it can be disposed in landfill is mechanical biological treatment as this option can lead to the material to be landfilled being relatively harmless and not so potent to generate methane and leachate (Eunomia, 2015). A schematic representation of the process is shown in Figure 25 below.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

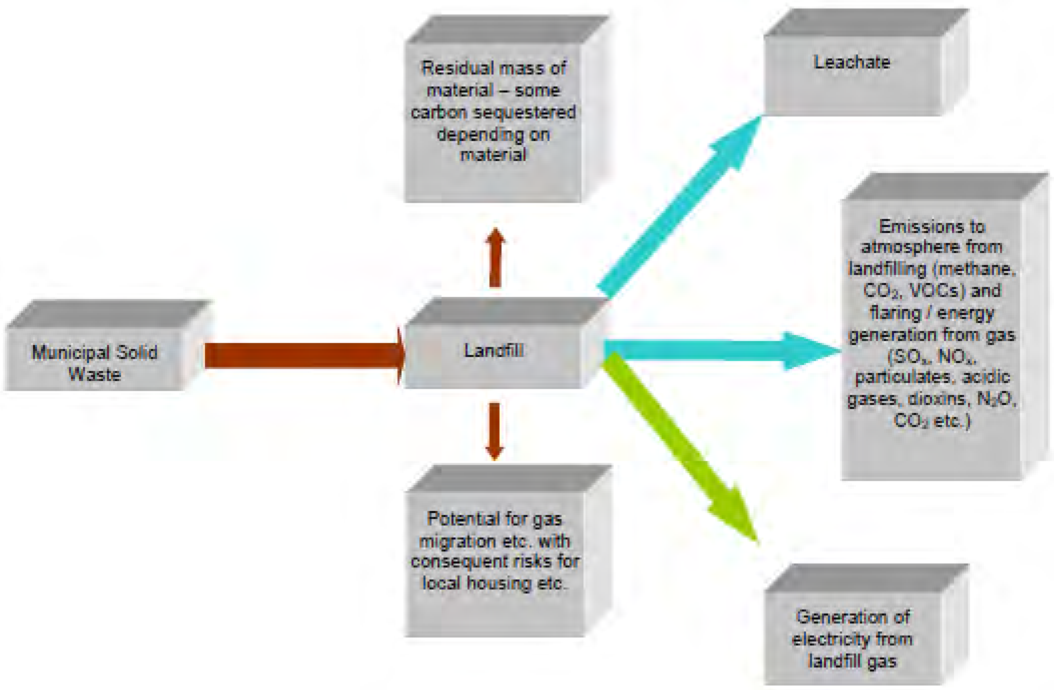


Figure 25: Landfill option (Eunomia, 2015)

An important point in relation to landfill is aftercare management which typically includes monitoring of emissions (e.g. leachate and gas) and receiving systems (e.g. groundwater, surface water, soil, and air) and maintenance of the cover and leachate and gas collection systems (Laner et al., 2012). Regulations specify a minimum period of aftercare for which funding must be accrued; for example, the European Landfill Directive (European Commission, 1999) specifies a period of at least 30 years of aftercare as a basis.

Summarising an overall picture of the treatment options across Europe expresses in kg/capita can be seen in Figure 26. As it is obvious there is a strong difference between countries in the North and South of Europe.

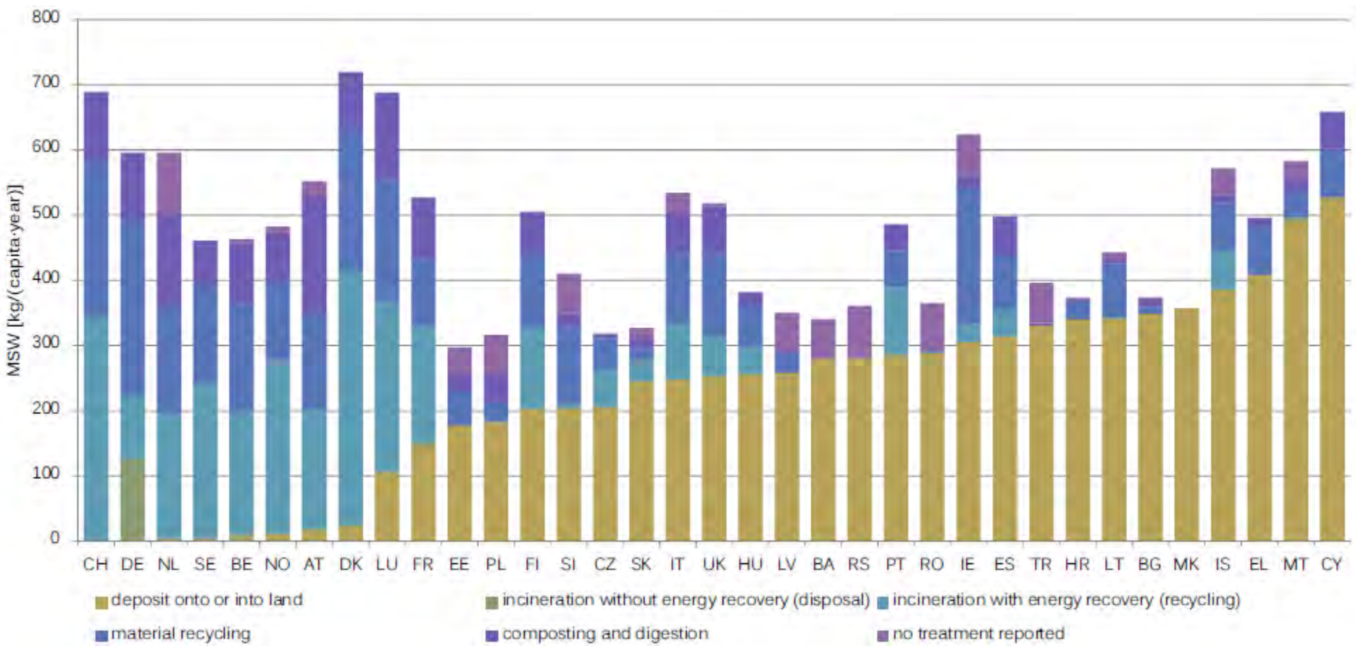


Figure 26: Treatment of MSW across Europe – kg per capita in 2011 (FhG-IBP, 2014)

2.4 Circular economy and closing the loop

As it has been presented in the previous sections, waste is an issue that has been raising awareness in the past years. Relevant regulations and directives are trying to find new and effective ways to manage it appropriately and efficiently. Yet implementation of these rules differs by country and sometimes even by region. The fact is that waste arisings continue to rise and our world cannot sustain the uncontrolled disposal of waste anymore. New and improved technologies are emerging which can help manage waste in a more efficient way which is more beneficial in the long run as well. The model that used to run up until today is that of the linear economy when it comes to waste management whereas natural resources were extracted and used and then disposed of usually at landfills (Figure 27).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Figure 27: The linear economy and waste management (UNEP, 2015)

Lately systems analysis techniques have been applied to handle MSW streams through a range of integrative methodologies, with a total of five system engineering models and nine system assessment tools in this field (Chang et al., 2011). These models contain, among others, systems engineering models like Cost Benefit Analysis (CBA), prediction and simulation models and optimization models (OM). Similarly, they may comprise system assessment tools embracing management information and decision support/expert systems, the development of scenarios, life cycle assessment or inventory, risk and environmental impact assessments, strategic environmental and socioeconomic assessments and sustainable assessment (Pires et al., 2011).

Thus with these techniques, nowadays the focus has moved upstream, addressing the problem from the beginning; this starts at the designing of waste, preventing it, reducing both the quantities and the uses of hazardous substances, minimising and reusing resources and where residuals still occur, keeping them concentrated and separated to preserve their potential value for recycling and recovery and prevent them from contaminating anything else with economic value after recovery (UNEP, 2015).

The main idea is to move away from 'waste disposal' to 'waste management' and from 'waste' to 'resources' (UNEP, 2015). Moving towards a circular economy as presented in Figure 28 creates a challenge of its own, as it demands changing our way of thinking and managing waste. Landfill is and need to be considered as the last possible resort for waste. As the figure illustrates the biological and technical nutrients should be kept in separate loops in order to maintain high quality and make it possible to circulate effectively; the smaller the cascading loop the higher the value kept in the resource and with less need for adding energy and other resources to keep it circulating (Berndtsson, 2015).

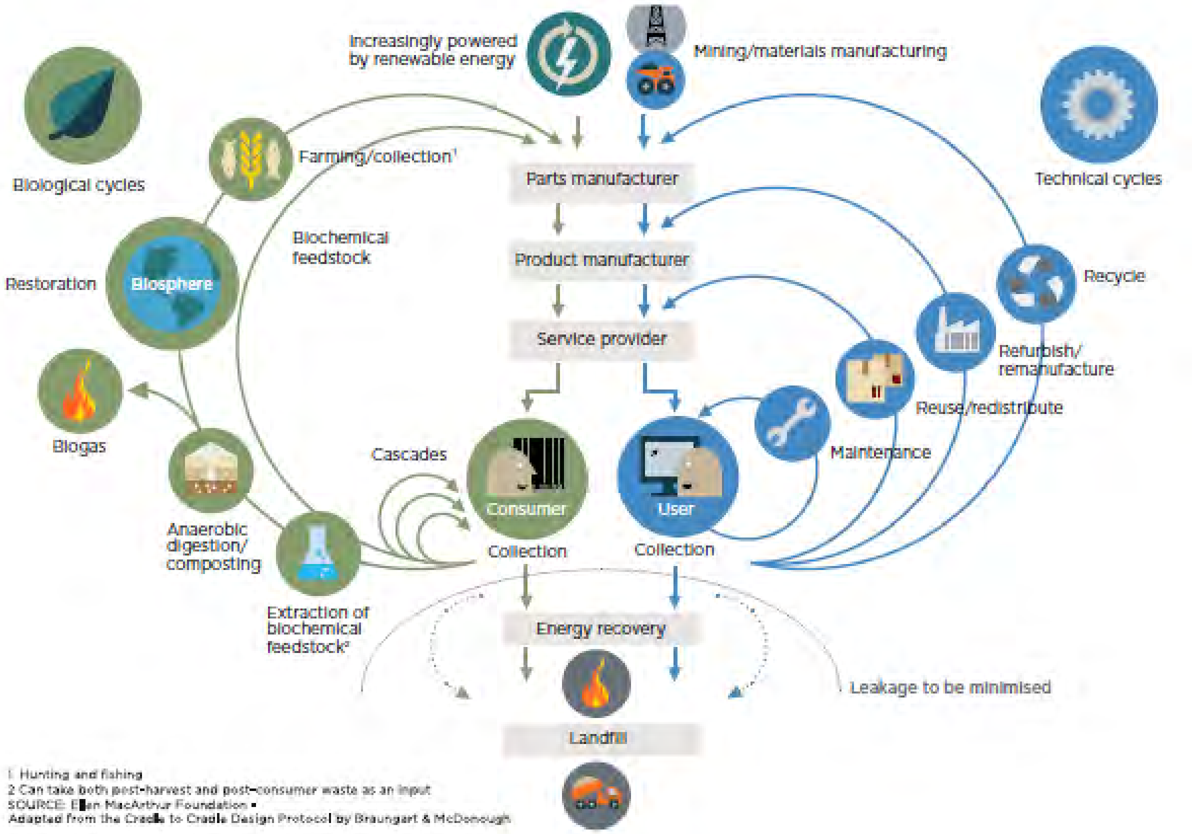


Figure 28: Moving towards a circular economy (UNEP, 2015)

Regulations already exist in the EU on those regards, the only thing left to do is put them in practice. As it has been presented in the previous sections, prevention and resource efficiency are two of the main drivers towards the circular economy. However the uniqueness of the Circular Economy comes from two interrelated ideas, the closed-loop economy and 'design to re-design' approaches, demonstrating new concepts of system, economy, value, production, and consumption (Murray et al., 2015). Therefore the idea of the circular economy is highly related to waste management under the umbrella of resources management at the same time and demands further research. Moreover in relation to the circular economy an important area that needs to be taken into account is the energy sector and more specifically energy efficiency with regards to MSW arisings.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

2.5 Energy efficiency and MSW in the circular economy

Energy efficiency improvement can provide many benefits apart from cost efficiency such as energy savings, air pollution control and GHG emission reduction as well as energy security and health benefits (Zhou et al., 2018). It is essential to combine technological options and implementation approaches to improve the energy recovery efficiency of the urban and industrial system and thus achieve low-carbon cities (Ohnishi et al., 2018).

Generally it is noticed that the global economy is highly reliant on fossil fuels such as oil, gas, and coal resulting in higher GHG emissions (Halkos and Tzeremes, 2013a; Fruergaard and Astrup, 2011). Due to the volatile price of oil and the environmental degradation occurring due to fossil fuels' use, a turn towards renewable energy sources has been noticed (Apergis and Payne, 2010). Along those lines the public has become more sensitive to environmental issues, therefore most countries will be forced to make real changes in their energy mix (Halkos and Tzeremes, 2012).

MSW can act as a source of energy through waste incineration; for instance in Denmark waste incineration currently supplies about 5% of the electricity demand and about 20% of the district heating demand (Fruergaard and Astrup, 2011). MSW can be grouped into three fractions: (1) mixed high calorific waste materials suitable for SRF production, (2) organic waste materials suitable for biological treatment and (3) mixed waste materials not fitting into the former two fractions (Fruergaard and Astrup, 2011).

Thus each fraction may require different treatment. At the same time it is noticed that the share of energy from renewable sources is also on the rise in the EU Member States as shown in Figure 29, showing also how far those countries are from achieving their 2020 target. So far Sweden, Finland, Denmark, Estonia, Croatia, Lithuania, Romania, Bulgaria, Italy, Czech Republic and Hungary have managed to accomplish this.

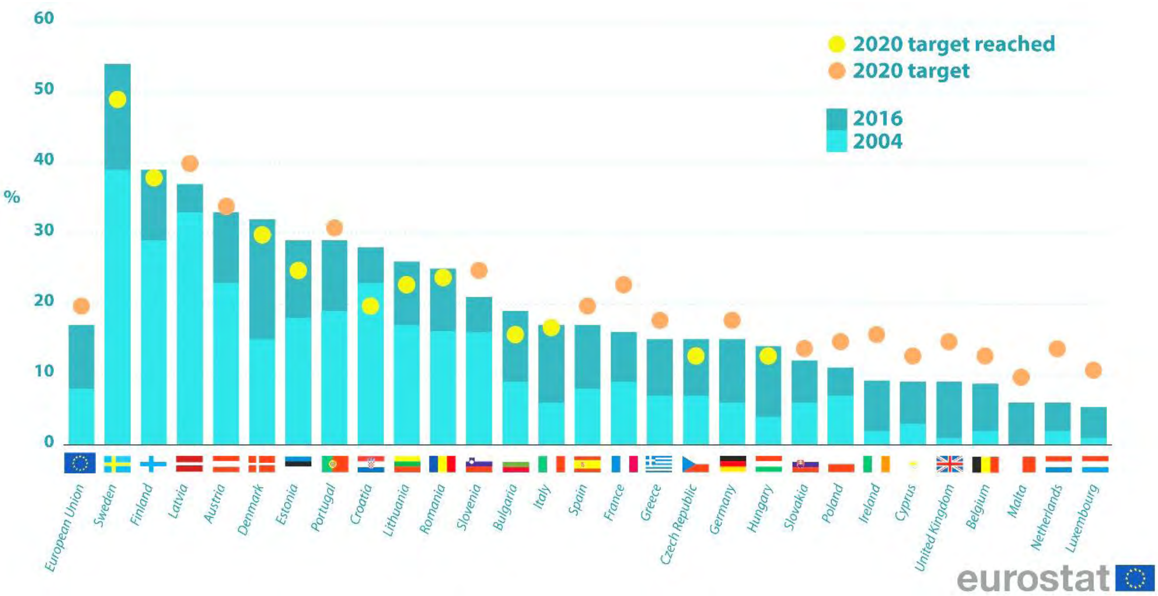


Figure 29: Share of energy from renewable sources 2004-2016 (in % of gross final energy consumption) (Eurostat data)

2.6 Cultural dimensions and waste management

As mentioned one main issue with waste generation nowadays is that although the legislations are in place in order to help get resources back, these tend to be overlooked as not much importance is given to the protection of the environment despite the financial contribution it may have. In those regards, the word “waste” can either be seen as a noun or a verb, whereas the noun “waste” attributes the fault to the item itself, the verb “to waste” attributes the fault to the party who neglects to appreciate the value of the item (Lee, 2017). Figure 30 presents the schematic life cycle of waste generation, which is composed of three main parts: 1. how and what kind of waste is generated in the economy, 2. society’s management of any purchased good and 3. units and connections of the MSW management and treatment systems.

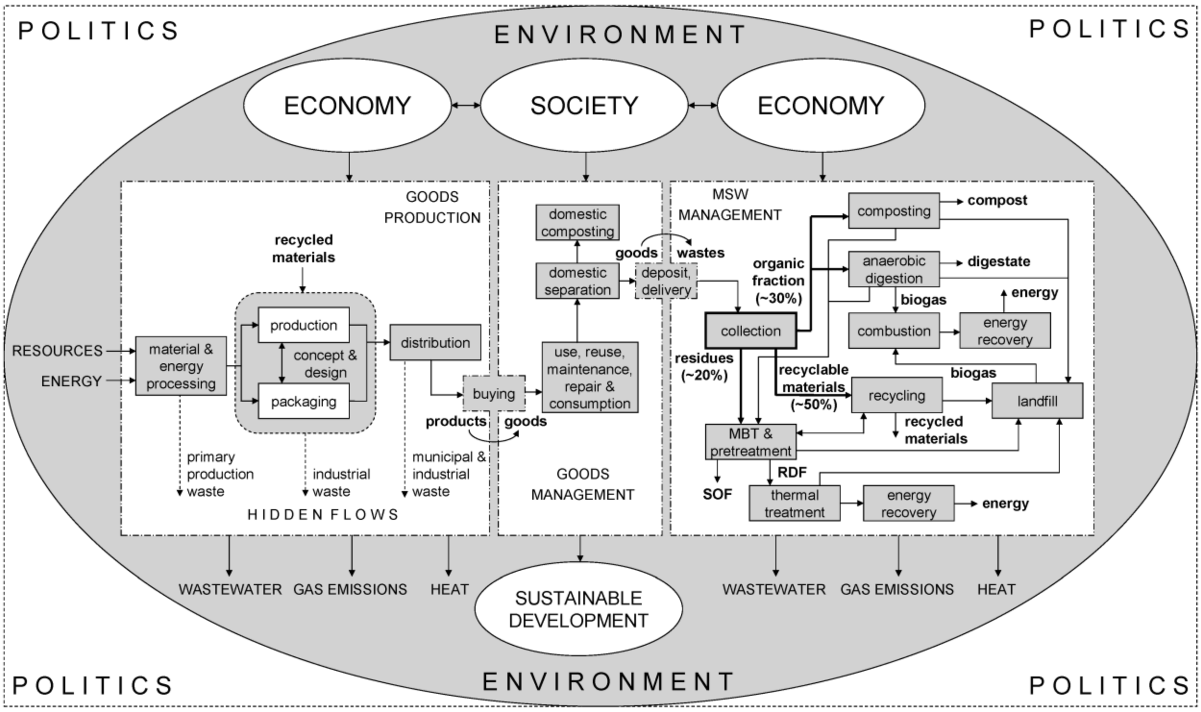


Figure 30: Schematic life cycle of waste generation (De Feo and Napoli, 2005)

Arguments prioritising culture as a prominent development factor exist for many years now, namely in 1905 Max Weber was the first one to raise awareness on the importance of a set of values to explain the success of industrial capitalism vis-a-vis pre-capitalist agrarian societies across Europe (El Leithy, 2017). The main focus of the present analysis is cultural formation and especially the current picture of 'waste culture' and public perception across EU member states. At this point it is essential to make the distinction between culture and society.

Culture is defined as the way of life, especially the general customs and beliefs, of a particular group of people at a particular time based on the Cambridge Dictionary. Cultural values are shared and constitute the broad goals that members of a society are encouraged to pursue (Williams, 1970; Schwartz, 1999). Hofstede (1980) defined culture as 'the collective programming of the mind which distinguishes the members of one human group from another'. Society on the other hand is a group of people sharing a common culture and social system (Parsons, 1951).

GSRT
GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I.
Hellenic Foundation for Research & Innovation

There are three sources of influence in those regards: the value culture in the surrounding society, the personal value priorities of organisational members and the nature of the organisation's primary tasks (Sagiv and Schwartz, 2007). Hence it stands to reason that people's perceptions, beliefs and values regarding the environment will be different among countries based on national culture characteristics which will result to different levels of countries' environmental performance as well (Hofstede et al., 2010). In relation to that there are different environmental policies which are reflected on their environmental performance levels (Halkos and Tzeremes, 2013b). The need for a convincing categorisation is obvious as it will enable (Lewis, 1990):

- The prediction of a culture's behaviour.
- The clarification as to why people did what they did.
- The avoidance of giving offence.
- The search for some kind of unity.
- The standardisation of policies.
- The perception of neatness.

Culture maintains a balance between humans, society and the physical environment and provides the context within which human activities take place (Roberts and Okereke, 2017). It is essential to integrate culture within the sustainability programmes as culture can greatly impact most societal functions, including waste management (Schneider, 1972). Many studies suggest that cultural values mainly influence the formation of green purchase intentions (Chekima et al., 2016). Therefore, the above mentioned cultural dimensions can serve as a valuable tool to analyse and evaluate the public's approach towards certain societal issues and in this case towards waste arisings in order to get the complete picture of the waste culture across these 22 EU Member States.

Waste could be considered as the final product of a specific production chain: wealth, consumption, waste (De Feo and De Gisi, 2010). 'Waste culture' can be examined through various perspectives such as moral, philosophical, societal etc., but what is important to note is that waste is everywhere and it is essential to understand people's mentality towards it (Lee, 2017). What is generally noticed is that in today's fast moving consumer – especially western – societies an unsustainable convenience culture has been formed (Hall, 2017).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

What is more this convenience culture is mainly output-oriented and brings with it waste arisings from all production processes (Lee, 2017). To overcome this culture of waste it would be appropriate to move towards an input-oriented approach, therefore in this production process one would start with the resources available, appreciate them and work forward to use them most effectively to generate value (Lee, 2017).

An important part of 'waste culture' formation also has to do with the availability of environmental information and the use of information as a policy tool. Thus this information will increase environmental awareness and concern leading to more sustainable consumption practices (Aini et al., 2002). Information also has the potential to persuade and create positive attitudes towards for instance the recycling system among the public (Petty and Cacioppo, 1986; Bator and Cialdini, 2000). Moreover environmental psychologists stress the fact that personal norms serve as moral obligations in environmental behaviour, which may be internalised social norms or norms deriving from higher order values (Schwartz, 1977; Hopper and Nielsen, 1991; Bratt, 1999).

Many studies of cultural values have focused extensively on nations. These include but are not limited to the following: 1. Hofstede's dimensions of national cultures (Section 2.6.1), 2. Trompenaars' and Hampden-Turner's cultural factors (Section 2.6.2), 3. Schwartz's cultural values (Section 2.6.3), 4. Inglehart's World Values Survey (Section 2.6.4), 5. GLOBE'S (Global Leadership and Organizational Behavior Effectiveness) cultural dimensions (Section 2.6.5) and 6. Lewis Model (Section 2.6.6). The empirical analysis will focus on cultural dimensions' data from the Hofstede and Schwartz models, these will be analysed in greater detail below. Furthermore a comparison between these two models is presented (Section 2.6.7).

2.6.1 Hofstede's cultural dimensions

Hofstede's cultural dimensions' theory is a framework for cross-cultural communication, developed by Geert Hofstede. Hofstede (1980) conducted an employee attitude survey from 1967 to 1973 within IBM's subsidiaries in 66 countries. The responses comprise of 117,000 questionnaires trying to investigate the respondents' 'values', which he defines as 'broad tendencies to prefer certain states of affairs over others' and which are according to him the 'core element in culture' (Hofstede, 1980; Halkos and Tzeremes, 2013c). Then he statistically analysed the collected data and constructed four national cultural indexes and found that there are four central and 'largely independent'

(Hofstede, 1983) dimensions of a national culture. Then he gave a comparative score on each of these dimensions.

As mentioned the original theory proposed four dimensions along which cultural values could be analysed: power distance (strength of social hierarchy). individualism-collectivism, uncertainty avoidance and masculinity-femininity (task orientation versus person-orientation) (Hofstede, 1980). Furthermore a fifth dimension was added by research conducted in Hong Kong, long-term orientation, this would then cover aspects of values not included in the original paradigm, then in 2010, Hofstede added a sixth dimension, indulgence versus self-restraint. In more detail the dimensions of national cultures are presented below (Hofstede, 1980; 1991; 2011):

a. Power distance index (PDI): presents the extent to which the less powerful members of organisations and institutions believe that power is distributed unequally. Countries with a higher degree of the Index are more hierarchical, whereas a lower degree of the Index shows a questioning towards authority figures and those who want the redistribution of power. As it is expected power distance is perceived differently across nations and Figure 31 presents the world image of this index.

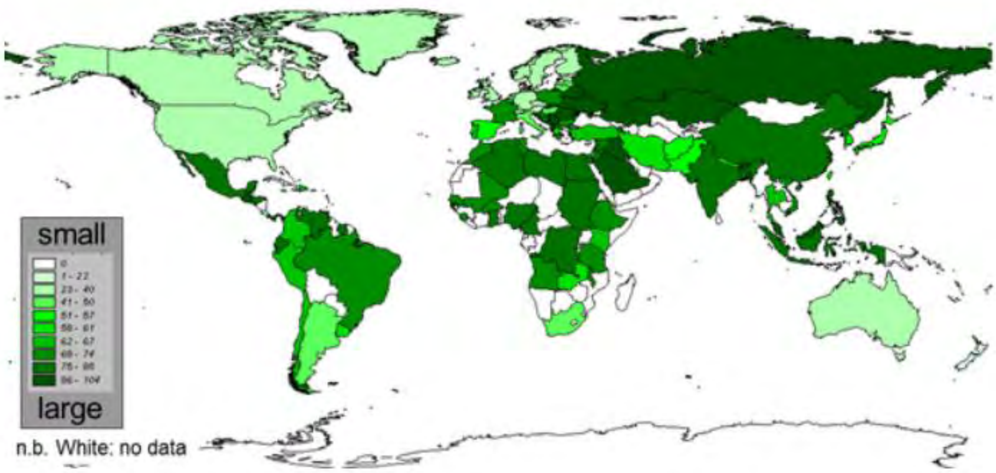


Figure 31: Power distance world map (Hofstede, 2018)

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

b. Individualism vs. collectivism (IDV): shows the integration of people in each culture into groups. Individualistic societies have loose ties and emphasize the "I" versus the "we." On the contrary collective societies show a close tie in extended families and into groups. Similarly to power distance, nations across the world view individualism and collectivism differently as well, Figure 32 presents the world image of this index.

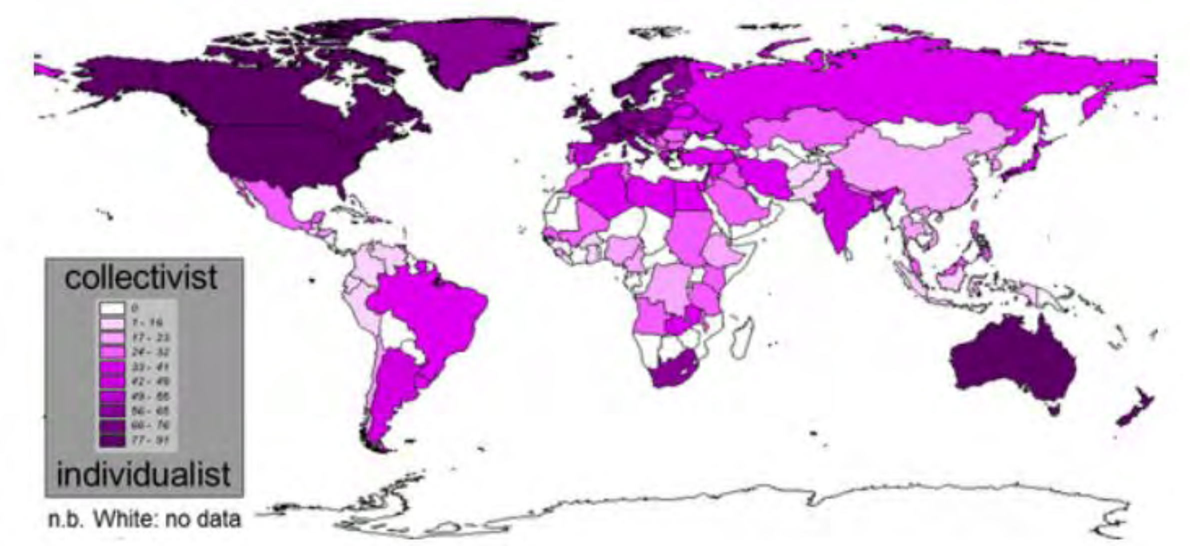


Figure 32: Individualism vs. collectivism world map (Hofstede, 2018)

c. Uncertainty avoidance index (UAI): shows a society's tolerance for ambiguity and the degree to which people embrace or avert an event of something unexpected, unknown or away from the status quo. Societies with a high degree of this index show great value in guidelines, laws, and generally rely on absolute truth. A lower degree in this index shows more acceptance of differing thoughts/ideas. Graphically these different attitudes can be seen in Figure 33 presenting the world image of this index.

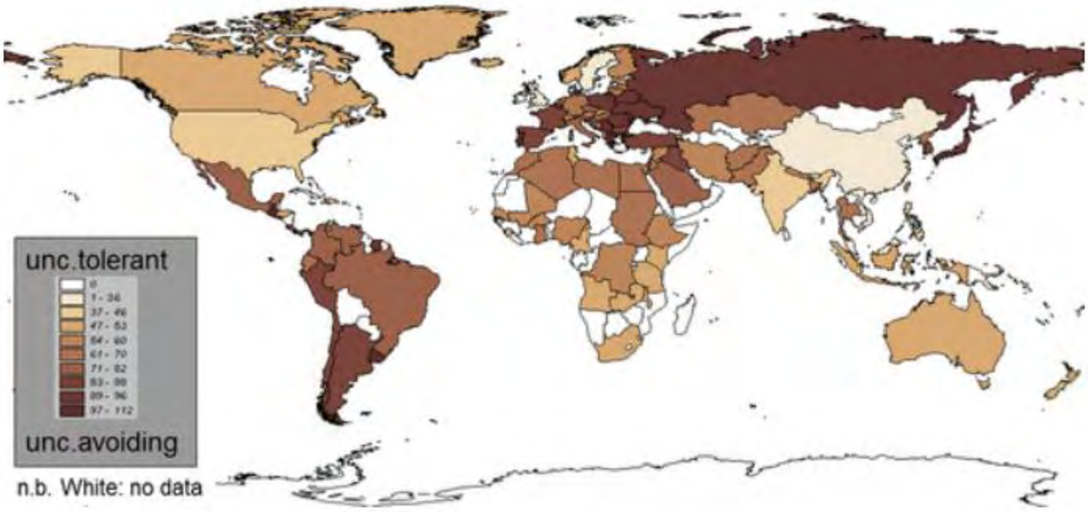


Figure 33: Uncertainty avoidance index world map (Hofstede, 2018)

d. Masculinity vs. femininity (MAS): masculinity in a society means preference for achievement, heroism, assertiveness and material rewards for success. In feminine societies the same ideas are shared between men and women. In more masculine societies, women are more emphatic and competitive, but notably less emphatic than men, meaning there is still a gap between how men and women are perceived. As it is expected masculinity vs. femininity is perceived in a different way across nations and Figure 34 presents the world image of this index.

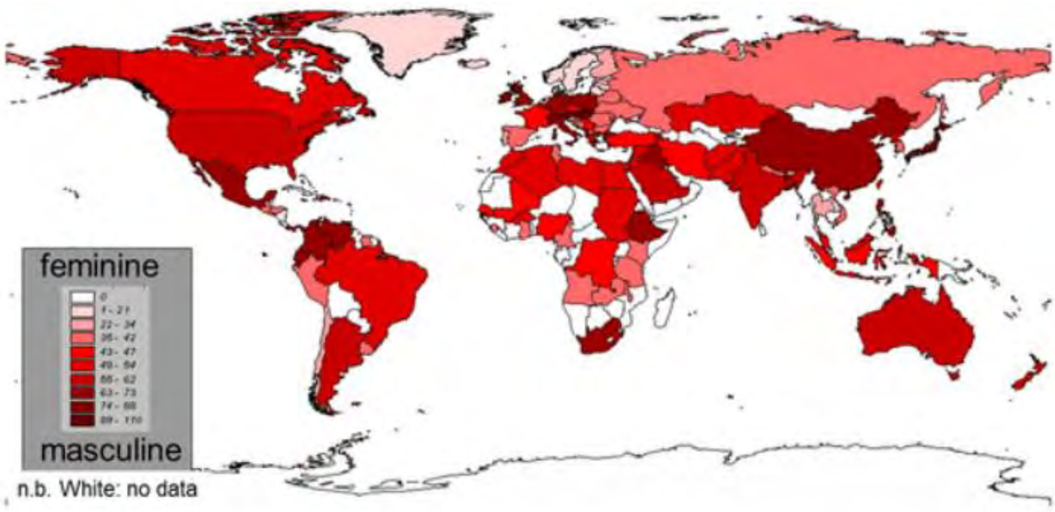


Figure 34: Masculinity vs. femininity world map (Hofstede, 2018)

e. Long-term orientation vs. short-term orientation (LTO): has to do with the connection of the past with the current and future actions. A lower degree of this index is present in societies which value traditions. Societies with a high degree in this index are more adaptive and circumstantial. Again a nation's orientation differs to others worldwide, Figure 35 presents the world image of this index.

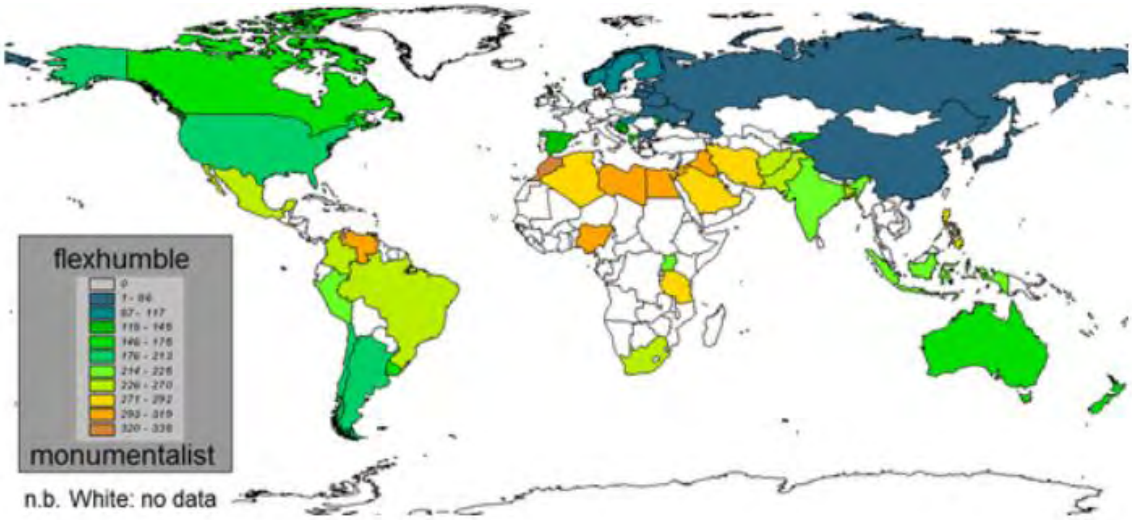


Figure 35: Long-term(flexhumble) vs. short term (monumentalist) orientation world map (Hofstede, 2018)

f. Indulgence vs. restraint (IND): is a measure of happiness; whether or not simple joys are fulfilled. In indulgent societies natural desires are related to human satisfaction and joy, whereas in restraint focused cultures, people control the satisfaction of needs and regulate it by means of strict social norms. Figure 36 presents the world image of this final index and obviously since it's the latest index added, data are limited in relation to the other dimensions.

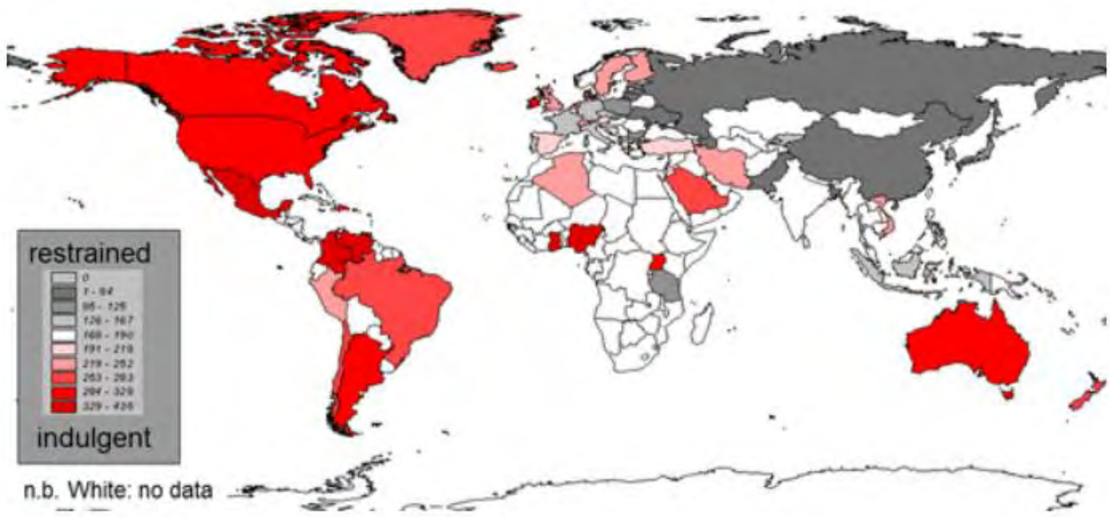


Figure 36: Indulgence vs. restraint world map (Hofstede, 2018)

Even though Hofstede's work has been widely criticised, the size of the sample and the dimensions' stability over time have provided credibility and reliability (Hofstede, 2001; Kogut and Singh, 1988). His theory has been widely used in several fields as a paradigm for research, particularly in cross-cultural psychology, international management and cross-cultural communication. It continues to be a major resource in cross-cultural fields and has inspired a number of other major cross-cultural studies of values, as well as research on other aspects of culture, such as social beliefs (Halkos and Tzeremes, 2010).

A lot of criticism has been done on the empirical validity of Hofstede's framework (Shackleton and Ali, 1990; Sondergaard, 1994; Triandis, 1982; Yoo and Donthu, 1998). Based on the generalisation of the research findings the main disadvantage presented is the fact that the sample used, only focused on one large multinational company (Triandis, 1982; Yoo and Donthu, 1998). Furthermore Yoo and Donthu (1998) suggest that the dimensions of national culture could only refer to that period of study. Despite this criticism Hofstede's framework is generally accepted as the most inclusive framework of national cultural values (Kogut and Singh, 1988; Sondergaard, 1994; Yoo and Donthu, 1998). Thus it is of great value and shows significant correlations with economic, social and geographic indicators (Kogut and Singh, 1988). Furthermore, Hofstede's dimensions of national culture have been found to be valid, reliable and stable over time (Bond, 1988; Kogut and Singh, 1988; Yoo and Donthu, 1998).

2.6.2 Trompenaars' and Hampden-Turner's seven dimensions

Trompenaars Hampden-Turner (THT) is a research driven consulting firm that was founded about 25 years ago by Fons Trompenaars and Charles Hampden-Turner (Trompenaars and Hampden-Turner, 2010). The seven dimensions of Trompenaars' and Hampden-Turner's cultural factors are (Trompenaars and Hampden-Turner, 1997; 2010):

1. Universalism vs. particularism: The dimension universalism-particularism concerns the standards by which relationships are measured. Universalist societies tend to feel that general rules and obligations are a strong source of moral reference. Universalists are inclined to follow the rules - even when friends are involved - and look for "the one best way" of dealing equally and fairly with all cases. They assume that their standards are the right standards and they attempt to change the attitudes of others to match theirs.
2. Individualism vs. collectivism: The dimension individualism versus collectivism is about the conflict between an individual's desire and the interests of the group he/she belongs to. In a predominantly individualistic culture, people are expected to make their own decisions and to only take care of themselves and their immediate family. Such societies assume that quality of life results from personal freedom and individual development.
3. Analysing vs. integrating: Generally, people from specifically oriented cultures begin by looking at each element of a situation. They analyse the elements separately, then put them back together again - viewing the whole is the sum of its parts. Specifically oriented individuals concentrate on hard facts. People from diffusely oriented cultures see each element in the perspective of the complete picture.
4. Inner-directed vs. out-directed: The internal versus external control dimension concerns the meaning people assign to their environment. People who have an internally controlled mechanistic view of nature - a belief that one can dominate nature – usually view themselves as the point of departure for determining the right action. In contrast to this, cultures with an externally controlled (or organic) view of nature - which assumes that man is controlled

by nature - orient their actions towards others. They focus on the environment rather than on themselves.

5. Time as sequence vs. time as synchronisation: The time orientation dimension has two aspects: the relative importance cultures give to the past, present and future, and their approach to structuring time. If a culture is predominantly oriented towards the past, the future is often seen as a repetition of past experiences. In a culture predominantly oriented towards the present, day-by-day experiences tend to direct people's lives. In a future-oriented culture, most human activities are directed toward future prospects. In this case, the past is not considered to be vitally significant to the future.

6. Sequentialism and synchronism form the different approaches achieved status vs. ascribed status: The dimension achievement-ascription focuses on how personal status is assigned. While some societies accord status to people on the basis of their performance, others attribute it to them by virtue of age, class, gender, education etc. While achieved status refers to action and what you do, ascribed status refers to being and who you are.

7. Equality vs. hierarchy: This dimension focuses on the degree to which people express emotions, and the interplay between reason and emotion in human relationships. Every culture has strong norms about how readily emotions should be revealed. In cultures high on affectivity, people freely express their emotions: they attempt to find immediate outlets for their feelings. In emotionally neutral cultures, one carefully controls emotions and is reluctant to show feelings. Reason dominates one's interaction with others. In a neutrally oriented culture, people are taught that it is incorrect to overtly show feelings. In an affectively oriented culture, it is accepted to show one's feelings spontaneously.

2.6.3 Schwartz's cultural dimensions

Schwartz (1994) was actually one of those researchers who raised several serious concerns regarding Hofstede's cultural dimensions. First, he suggests that Hofstede's dimensions are not thorough enough as the original survey's goal was not to analyse societies' cultures and thus may not show the complete picture. Secondly Hofstede's sample of countries is not a complete reflection of national cultures and if more were added to the sample results could have been different. Finally as the sample was drawn from IBM employees it is not representative of the population of the relevant country in terms of education and background for instance.

According to Schwartz (1999) cultural dimensions need to be analysed and clarified in order to understand the value people place on them. Many scholars support Schwartz's opinion and approach, but for instance Steenkamp (2001) although recognising the value of Schwartz's model, he still doesn't give up on using Hofstede's model as it is not fully tested like Hofstede's one.

Schwartz (1992) created a comprehensive set of 56 individual values recognised across cultures, thus covering all value dimensions. He also examined the relevant meaning of these values across different countries and reduced them to 45. Following that he surveyed school teachers and college students from 67 countries as of 1988, averaged the scores on each of the 45 value items for each country, and used smallest-space analysis to find out if these values differ in the various countries (Drogendijka and Slangen, 2006).

This procedure concluded with the creation of seven dimensions, namely 'conservatism', 'intellectual autonomy', 'affective autonomy', 'hierarchy', 'egalitarian commitment', 'mastery', and 'harmony' (Schwartz, 1994, 1999). As explained by Schwartz (1999), certain pairs of cultural value orientations share relevant assumptions. The conflicts and compatibilities among the orientations yield the following coherent circular order of orientations: embeddedness, hierarchy, mastery, autonomy, egalitarianism, harmony and return to embeddedness.

Schwartz's value dimensions offer several potential advantages compared to Hofstede's dimensions (Ng et al., 2006):

- Schwartz's values are theoretically derived.
- They are more comprehensive.
- They have been tested with more recent data (collected between 1988 and 1992) with two samples (student and teacher samples).
- The samples were obtained from more diverse regions, including socialist countries (e.g. former Eastern European countries).

Schwartz's cultural values are presented in Figure 37.

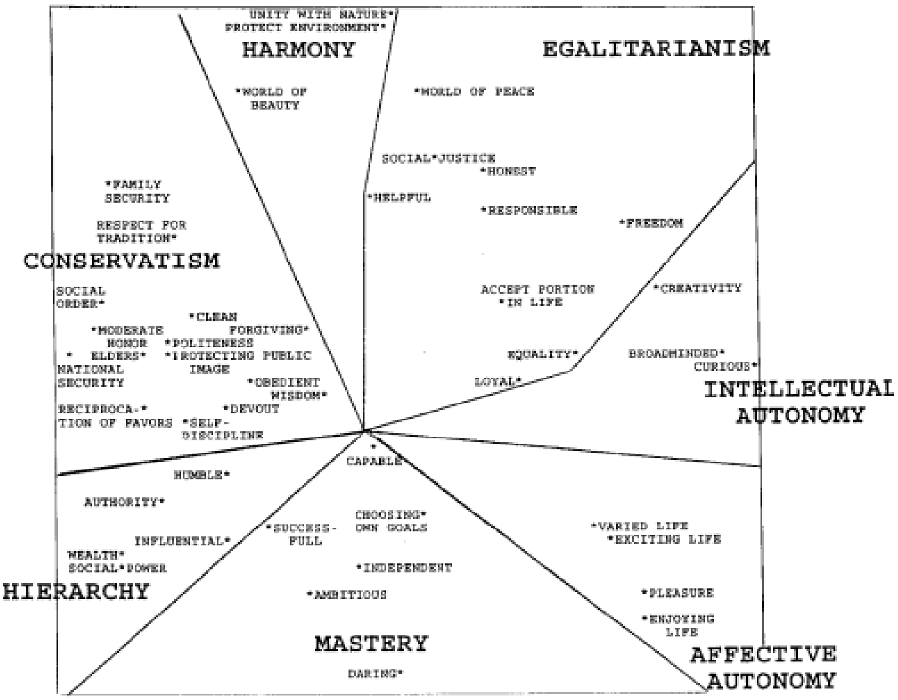


Figure 37: Schwartz's cultural values (Schwartz, 1994)

2.6.4 Inglehart's model

Political scientists Ronald Inglehart of the University of Michigan and Christian Welzel of Luephana University in Germany put forth their best effort by analysing data and plotting countries on a culture map (Sterbenz, 2014). Their system stems from the World Values Survey (WVS), the largest "non-commercial, cross-national, time series investigation of human beliefs and values ever executed," which dates to 1981 and includes nearly 400,000 respondents from 100 countries. The WVS has over the years demonstrated that people's beliefs play a key role in economic development, the emergence and flourishing of democratic institutions, the rise of gender equality, and the extent to which societies have effective government (WVS, 2015). The cultural map is presented in Figure 38.

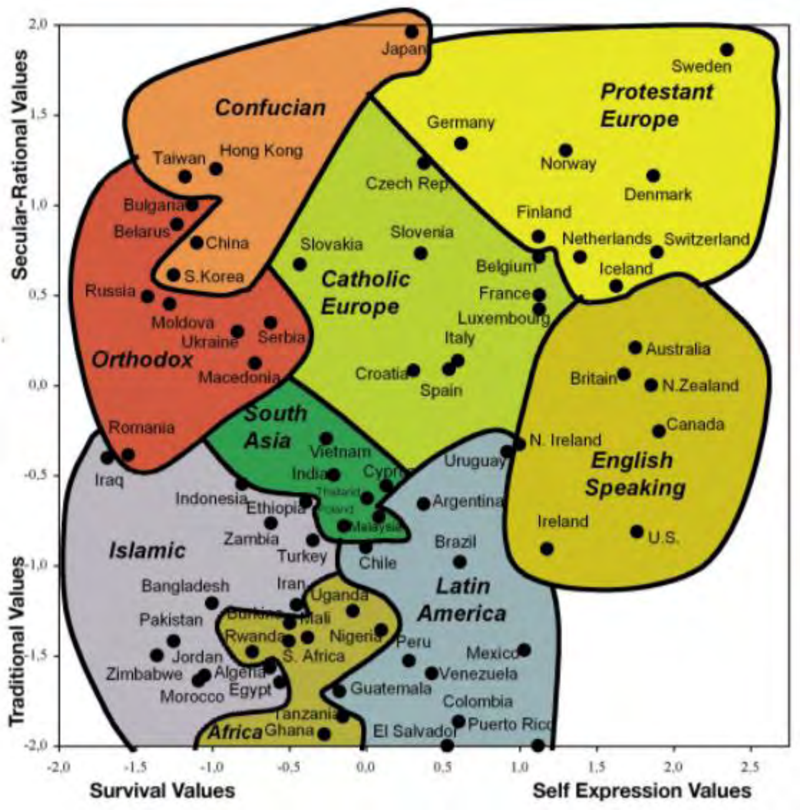


Figure 38: WVS wave 5 (WVS, 2008)

On the y-axis, traditional values emphasize the importance of religion, parent-child relationships, and authority, according to WVS. People who embrace these tend to reject divorce, abortion, euthanasia, and suicide. These societies usually exhibit high levels of nationalism and national pride, too. In the US, these values would likely align more with conservative ideologies. On the x-axis, survival values revere economic and physical security and safety and are linked to low levels of trust and tolerance. On the other side, self-expression values give high priority to protecting the environment, promoting gender equality, and tolerating foreigners and gays and lesbians.

However, the attitudes among the population are also highly correlated with the philosophical, political and religious ideas that have been dominating in the country. Secular-rational values and materialism were formulated by philosophers and the left-wing politics side in the French revolution and can consequenlty be observed especially in countries with a long history of social democratic or socialistic policy, and in countries where a large portion of the population have studied philisophy and science at universities. Survival values are characteristic for eastern-world countries and self-expression values for western-world countries. In a liberal post-industrial economy, an increasing share of the population has grown up taking survival and freedom of thought for granted, resulting in that self-expression is highly valued. Examples include (VWS, 2015):

- Societies that have high scores in Traditional and Survival values: Zimbabwe, Morocco, Jordan, Bangladesh.
- Societies with high scores in Traditional and Self-expression values: the US, most of Latin America, Ireland.
- Societies with high scores in Secular-rational and Survival values: Russia, Bulgaria, Ukraine, Estonia.
- Societies with high scores in Secular-rational and Self-expression values: Sweden, Norway, Japan, Benelux, Germany, France, Switzerland, Czech Republic, Slovenia, and some English speaking countries.

2.6.5 GLOBE'S dimensions

GLOBE is the acronym for "Global Leadership and Organizational Behavior Effectiveness," a 62-nation, 11-year study involving 170 researchers worldwide (Grove, 2015a). Conceived in 1991 by Robert J. House of the Wharton School of the University of Pennsylvania, the GLOBE Project directly involved 170 "country co-investigators" based in 62 of the world's cultures as well as a 14-member group of coordinators and research associates. This international team collected data from 17,300 middle managers in 951 organizations. They used qualitative methods to assist their development of quantitative instruments. In order to accurately and sensitively record the nuances of local meanings, all instruments were developed in consultation with members of each target culture, and instrument translation was done with enormous care.

Specific attention also was paid to the effect of "response bias" on data-gathering and -analysis. Relevant previous literature was exhaustively reviewed and, as appropriate, applied (making the book being overviewed here a veritable bibliographic goldmine). Ultimately, 27 research hypotheses were tested (Grove, 2015b). The Nine Units of Measurement or "Cultural Dimensions" are: Performance Orientation, Uncertainty Avoidance, In-Group Collectivism, Power Distance, Gender

Egalitarianism, Humane Orientation, Institutional Collectivism, Future Orientation and Assertiveness and these are further presented below (House et al., 2004).

1. The cultural dimension named "performance orientation" emerged from the research as exceptionally important. It “reflects the extent to which a community encourages and rewards innovation, high standards, excellence, and performance improvement”.

2. The cultural dimension named "uncertainty avoidance" also emerged from the research as very important. It is "the extent to which a society, organization, or group relies on social norms, rules, and procedures to alleviate the unpredictability of future events”. An alternative way of thinking about uncertainty avoidance is, that it’s about the extent to which ambiguous situations are felt as threatening – i.e., about the extent to which deliberate measures (such as making and enforcing rules and procedures) are taken to reduce ambiguity.

3. The findings about "in-group collectivism" are important because this cultural dimension emerges as a strong predictor of the two most widely admired characteristics of successful leaders. In-group collectivism is “the degree to which individuals express pride, loyalty, and cohesiveness in their organizations or families”.

4. The findings concerning "power distance" are interesting primarily because they failed to confirm a relationship expected by the researchers. Power distance as “the extent to which a community accepts and endorses authority, power differences, and status privileges”.

5. The findings for "gender egalitarianism" also are significant because it is one of the predictors of the most widely admired characteristic of successful leaders. Gender egalitarianism is “the degree to which a collective minimizes gender inequality”.

6. "Humane orientation" is defined as “the degree to which an organization or society encourages and rewards individuals for being fair, altruistic, friendly, generous, caring, and kind to others".

7. Characteristics of societies that have high and low humane orientation include the following "Institutional collectivism" is defined as “the degree to which organizational and societal institutional practices encourage and reward collective distribution of resources and collective action”.

8. "Future orientation" is “the degree to which a collectivity encourages and rewards future-oriented behaviors such as planning and delaying gratification”.

9. "Assertiveness" is "the degree to which individuals are assertive, confrontational, and aggressive in their relationships with others".

In summary these are presented inTable 3.

Table 3: Globe's dimensions

Dimensions	**Definitions**
Performance Orientation	Level at which a society values and rewards individual performance and excellence.
Uncertainty Avoidance	The extent to which members of collectives seek orderliness, consistency, structure, formalised procedures and laws to cover situations in their daily lives.
In-group Collectivism	Level at which a society values cohesiveness, loyalty and pride in their families and organisations.
Power Distance	The degree to which members of an organisation or society expect and agree that power should be shared unequally.
Gender Egalitarianism	Level at which a society values gender equality and lessens role differences based gender.
Institutional Collectivism	Level at which a society values and rewards 'collective action and resource distribution'.
Humane Orientation	Ideas, values and prescriptions for behaviour associated with the dimension of culture at which a society values and rewards altruism, caring, fairness, friendliness, generosity and kindness.
Future Orientation	The extent to which members of a society organisation believe that their current actions will influence their future, focus on investment in their future, believe that they will have a future that matters, believe in planning for developing their future and look far into the future for assessing the effects of their current actions.
Assertiveness	A set of social skills or a style of responding amendable to training or as a facet of personality.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

This first step allowed GLOBE (Figure 39) to place 60 of the 62 countries into country clusters. Cultural similarity is greatest among societies that constitute a cluster; cultural difference increases the farther clusters are apart. For example, the Nordic cluster is the most dissimilar from the Eastern European.

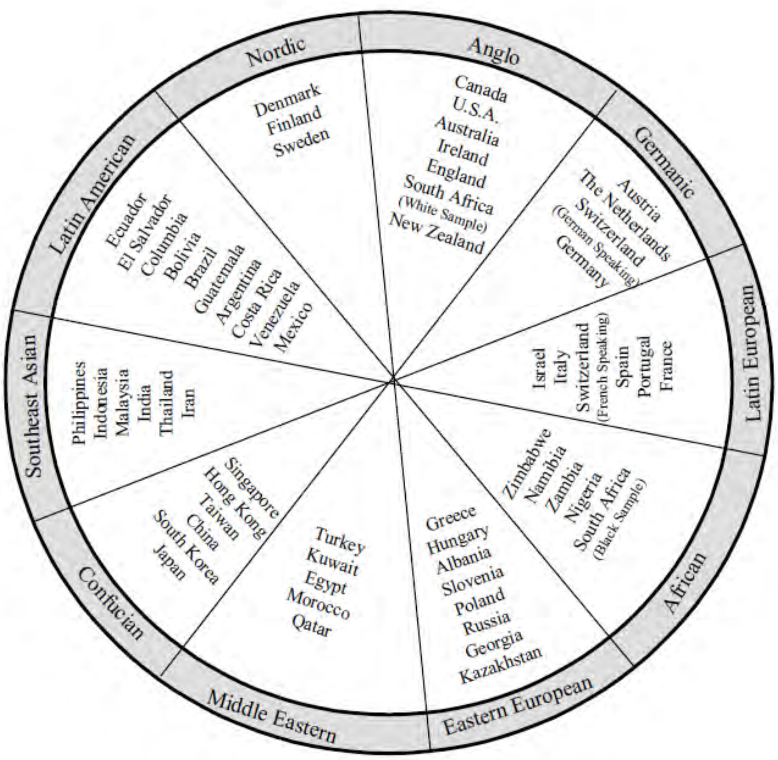


Figure 39: Country Clusters According to GLOBE (House et al., 2004)

2.6.6 Lewis' model

The Lewis Model is a cross-century tool which defines and simplifies the blueprint for cultural analysis. It was conducted to 50,000 executives taking residential courses and more than 150,000 online questionnaires to 68 different nationalities (Lewis, 1990). The main categories of this model are: Linear-Active, Multi-Active and Reactive cultures, which can be seen graphically on Figure 40, where countries are placed according to their dominant characteristics.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

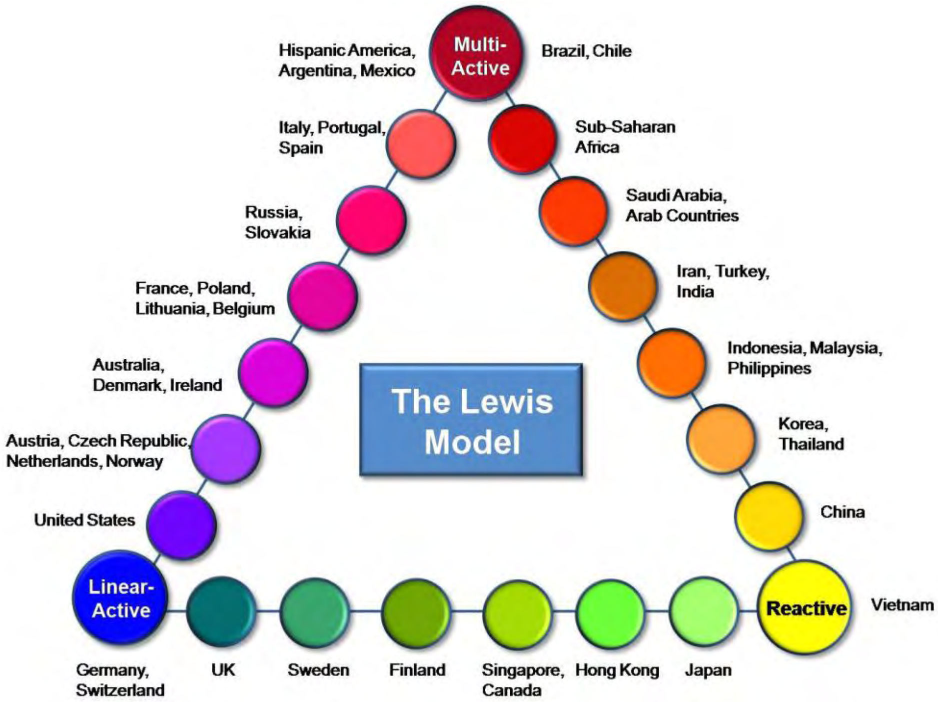


Figure 40: The Lewis Model (Lewis, 1990)

According to Lewis (1990) people in linear-active cultures generally demonstrate task orientation. They look for technical competence, place facts before sentiment, logic before emotion; they are deal-orientated, focusing their own attention and that of their colleagues on immediate achievements and results. They are orderly, stick to agendas and inspire people with their careful planning.

Multi-active cultures have people that are much more extrovert, rely on their eloquence and ability to persuade and use human force as an inspirational factor. They often complete human transactions emotionally, investing the time to developing the contact to the limit. Such people are great networkers, working according to people-time rather than clock-time.

People in reactive cultures are equally people-orientated but dominate with knowledge, patience and quiet control. They display modesty and courtesy, despite their accepted seniority. They create a harmonious atmosphere for teamwork. Subtle body language replaces excessive words. They know their companies well, giving them balance and the ability to react to a web of pressures. They are also paternalistic.

2.6.7 Comparisons and similarities between some of the models

It is rather difficult to compare and constrast the above mentioned models as these are based on different assumptions and have taken into account different groups of people and in diverse settings. Also only a few researchers have attempted to deal with this topic. The Hofstede and Schwartz models have been contrasted by some researchers and both have been criticised as well. In those regards Schwartz (1994) argued that his value types were different to Hofstede dimensions, as they were:

''. . . based on different theoretical reasoning, different methods, a different set of nations, different types of respondents, data from a later historical period, a more comprehensive set of values, and value items screened to be reasonably equivalent in meaning across cultures''.

He also suggested that his framework included Hofstede's dimensions either way. Both Hofstede (1980) and Schwartz (1994) identified national cultural dimensions that could be used to compare cultures. Hofstede prepared his framework empirically, while Schwartz developed his theoretically while both scholars empirically examining their frameworks using large-scale multi-country samples and finding greater cultural differences between countries than within countries, suggesting the frameworks could be used to compare countries (Ng et al., 2006).

Brett and Okumura (1998) believe that Schwartz's framework is superior to Hofstede's because it is based on a conceptualisation of values, it was developed with systematic sampling and analysis techniques and its data are more recent. In addition to that the strong theoretical foundations of Schwartz's model are stressed by Steenkamp (2001), although he raises some concerns with regards to its few empirical applications. Furthermore, correlations have been examined between Schwartz's cultural domains and Hofstede's cultural dimensions as can be seen in Table 4.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Table 4: Correlations between Hofstede's and Schwartz's models (Schwartz, 1994)

Hofstede's cultural dimensions	Positive correlations	Negative correlations
Individualism vs. collectivism	Affective autonomy (0.43) Intellectual autonomy (0.53) Egalitarian commitment (0.51)	Conservatism (-0.56) Hierarchy (-0.51)
Power distance index	Conservatism (0.45)	Affective autonomy (-0.45)
Uncertainty avoidance index	Harmony (0.43)	
Masculinity vs. femininity	Mastery (0.56)	

Moreover Smith et al. (2002) also found significant correlations between three of Schwartz's dimensions and Hofstede's dimensions, namely Hofstede's individualism, power distance and uncertainty avoidance indexes. Also Steenkamp (2001) used factor analysis to assess a potential overlap between these dimensions and concluded with four dimensions, which were named autonomy versus collectivism, egalitarian versus hierarchy, mastery versus nurturance and uncertainty avoidance; therefore three of the four factors were related to dimensions from both frameworks. While the evidence presented above illustrates some overlap, there also appears to be many differences between these two frameworks that demand closer investigation for future research as well (Ng et al., 2006).

2.7 MSW and education

As it comes forward, MSW management is more than a technical issue and it is necessary to understand the relationship between demographic variables and environmental attitudes and behaviours (Zelezny et al., 2000; Bakopoulou and Kungolos, 2004). Therefore more space is given to public participation in decision making, as waste management is more than just a technical issue (Vergara and Tchobanoglous, 2012). Education has been shown to be closely related with the challenges associated with environmental degradation (Rickinson, 2001) and more specifically with the waste households throw away which is called as already mentioned MSW. Consequently, society's

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

awareness needs to be raised and it is essential to evaluate the level of knowledge and understanding of MSW practices as well as actions undertaken (Grodzinska-Jurczak, 2002).

The first environmental education approach has to do with the promotion of nature and outdoor study, essentially in primary schools and consequently with the conservation movement (Stevenson, 2007). Nature study evolved with the publication of Wilbur Jackman's Nature Study for the Common Schools in the United States of America in 1891 (Stapp, 1974) as well as rural studies in Britain (Wheeler, 1975).

Education includes both the formal options through the school system as well informal ones (such as demonstration projects for citizens and seminars) in order to enhance environmental knowledge and lead to pro-environmental attitudes (Grodzinska-Jurczak, 2002). Education is described as the mechanism for teaching people how to think, rather than what to think (Andrews, 2008). Some researchers have attempted to examine whether education actually affects environmental attitudes and behaviour, i.e. in relation to waste sorting and generally higher attention to the environment and health implications (Abrate and Ferraris, 2010).

To start with Duggal et al. (1991), Judge and Becker (1993), Reschovsky and Stone (1994) and Callan and Thomas (1997) show that education increases recycling practices. In relation to that Fullerton and Kinnaman (1999) found that households with higher educational levels generated less waste. Chen (2010) supports regional inequalities in socio-economical characteristics such as income, population density, age composition, unemployment rate and the education level can lead to differences in waste arisings.

Leppänen's et al. (2012) study in Finland concluded that the educational background had an influence on the environmental attitudes of mothers (those with a university education had the most positive environmental attitudes) but this had no effect on the environmental attitudes of fathers. Also neither parent's education background affected the environmental attitudes of their children. The researchers do note that the Finnish education system is open to all despite the financial situation or social class (Leppänen et al., 2012) which may explain these results.

On the other hand Tsai (2008) shows that based on his research education plays an essential part to the waste-recycling rate. Moreover Peer et al. (2007) find that the mother's level of education influences their children's' environmental attitudes. Fredrick et al. (2018) investigated influence of public education on solid waste management in Kampala city, Uganda and found that public education

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

is improving waste management in the city. Finally Kinnman and Fullerton (2000) argue that as people become more educated, the more aware they are of sustainable development and what it entails. Chen (2010) also identifies that education plays an important role in motivating pro-environmental behaviours such as recycling. Overall a more educated society tends to present higher learning and innovation capacity (Tsai, 2008).

All in all this Section tackled the main issues that will be the focus of the present Thesis. Firstly the main parts of MSW including relevant regulations, composition and infrastructure have been examined. Then the circular economy idea is introduced both in relations to MSW and energy. Following that the main parts comprising culture and more specifically 'waste culture' were analysed, as well as the educational level in relation to MSW. Based on this extensive literature review, the following section will provide the methodology that will be used in this Thesis and relevant studies that have used similar approaches as well.

3. Methodology and data

The methodological approach is critical as the potential of the findings to support decision making will depend on the validity of the assumptions and the calculations used. Therefore this work will employ the following techniques. Firstly a literature review has been conducted to evaluate the current situation and identify the challenges that need to be addressed. Further data analysis on current conditions will be performed in order to evaluate the performance indicators and map the present waste landscape through different approaches. The tools that will be used include Data Envelopment Analysis (DEA) and statistical programmes, i.e. Stata in combination with DEA. To start with the main elements of DEA are outlined in Section 3.1, whereas Section 3.2 presents the panel data econometric methods that will be employed. Finally the data that have been used in this Thesis are presented in Section 3.3.

3.1 Data Envelopment Analysis (DEA)

Section 3.1.1 introduces the topic of DEA with its main characteristics and then Section 3.1.2 addresses the issue of treating undesirable outputs in DEA. Moreover the issue of bias correction in DEA estimators is analysed in Section 3.1.3, along with the tests regarding the existence of constant or variable returns of scale (Section 3.1.4). Then case studies using DEA are presented in Section 3.1.5 regarding MSW efficiency and in Section 3.1.6 regarding energy efficiency.

3.1.1 Introduction

Most methods used in economic efficiency analysis are mainly quantitative, although qualitative approaches (such as brainstorming, SWOT analysis, the Delphi method) can be used too, usually to support quantitative findings attained through either (Soukopová, 2011; Kumar and Managi, 2009):

a) single-criterion techniques: integrating several indicators into one (e.g. multiple input-to-output ratios into a single efficiency score in the case of DEA) or

b) multi-criteria analysis: keeping individual criteria separate to obtain a wider angle for assessment, often including non-economic perspectives.

Environmental efficiency has been gaining a lot of attention and has both theoretical value and practical meaning (Song et al., 2012). According to Rovere et al. (2010) an approach is needed that considers the technical, socioeconomic, environmental and technological factors of the various alternatives and also suggested that multi-criteria analysis could be employed as well. Although there is a practical value in this approach, it only drew a few researchers' attention (Angelis-Dimakis et al., 2011).

In evaluating environmental efficiency, life-cycle approaches have been used. In those regards life-cycle thinking comes handy, which means examining all stages of a product's life and determine where there is room for improvement for instance to reduce environmental impacts and use of resources and generally avoid situations that create negative consequences (European Commission, 2010b).

With Life Cycle Assessment (LCA) one can estimate the environmental impacts of a process or product, based on the efficiency of the operations; if data is available for comparable settings, then performances can be benchmarked and relevant links can be established (Lozano et al., 2009). Inventory data are converted to a reduced number of environmental indicators which help identify hotspots and the relevant environmental improvement actions (Baumann and Tillman, 2004). LCA has also been employed to assess eco-efficiency of processes and products (Kuosmanen and Kortelainen, 2005; Kortelainen and Kuosmanen, 2007; Barba-Gutiérrez et al., 2008).

In addition to LCA, the majority of the parametric studies was aiming to analyse background variables such as the costs rather than the cost efficiency of waste collection and management (Rogge and De Jaeger, 2012). One exception to those studies, is the one conducted by Simões and Marques (2011) whose use of the parametric approach of the Stochastic Frontier Analysis (SFA) was employed to assess how the operational environment affects cost efficiency of waste management.

Data Envelopment Analysis (DEA) is a non-parametric approach that is used to measure the efficiency of certain Decision Making Units (DMUs) by employing linear programming techniques (Boussofiane et al., 1991). Generally the number of DMUs should be at least twice the number of inputs and output together, as this relationship may diminish the power of DEA (Golany and Roll, 1989). On the other hand, other researchers argue that the number of DMUs should be at least three times this number (Banker et al., 1989). But this kind of rules are not overbearing, meaning that in certain conditions there might be a significant number of DMUs and the model could still be efficient (Cook et al., 2014).

With DEA one can measure the efficiency performances of comparable DMUs which have multiple (usually) inputs and likewise outputs in conditions where there is accurate information on

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

their values and no knowledge about the production or cost function (Rogge and De Jaeger, 2012). DEA models can be divided into input-oriented ones, which minimise inputs while at least achieving the given output levels and output-oriented models, which maximise outputs without requiring more inputs (Ji and Lee, 2010).

DEA compares each DMU with all other and shows the ones that are operating inefficiently compared with the others by identifying best practice scenarios (Sherman and Zhu, 2006). One DMU is considered efficient, if there is no other operating point that is above this one; therefore if there is a point where less input is consumed or more output produced then the DMU is considered inefficient (Lozano et al., 2009).

Charnes et al. (1978) were the first to propose to measure the efficiency of DMUs under constant returns to scale (CRS), provided that all DMUs operate at their optimal level. Then Banker et al. (1984) employed variable returns to scale (VRS) in their model, thus accounting for the use of technical and scale efficiencies in DEA. One important benefit of DEA is that one doesn't need to make any assumptions regarding the relationship between inputs and outputs (Seiford and Thrall, 1990).

At this point it is essential to define efficiency, which is the ratio of output to input; a state of absolute efficiency is achieved if the greatest possible output per unit of input is accomplished and it is not possible to create any better conditions without altering technology or anything else in the production process (Sherman and Zhu, 2006). The total efficiency measure can be broken down into two distinctive layers:

a) allocative (or price) efficiency: an assessment of inputs and outputs being combined in an optimal proportion once prices are taken into account, usually defined by the first theorem of welfare economics and the Pareto efficiency criterion (Špaček et al., 2011).

b) technical efficiency (also X-efficiency): as put forward by Farrell (1957) and Koopmans (1951), measuring the pure relation between inputs and outputs while focusing on the minimisation of waste and the application of the best technologies (Mandl et al., 2008). The idea of Pareto optimality applies here too (Koopmans, 1951).

The DEA approach basically projects each DMU onto an efficient frontier and produces an optimisation model which in turn produces lower values for the inputs and higher values for the outputs (Lozano et al., 2009). The DEA frontier can act as the production frontier, but it must be noted

GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

that DEA is a method for performance evaluation and benchmarking against best-practice (Cook et al., 2014). DEA models are divided into three main categories which are the following:

1. Those taking undesirable outputs as inputs for processing (Berg et al., 1992; Hailu and Veeman, 2001), but this does not reflect the actual production process (Seiford and Zhu, 2002);
2. Those in which data for undesirable outputs are transformed and those are used in evaluating environmental efficiency (Seiford and Zhu, 2002; Hua et al., 2007)
3. Those considering the disposability of the production technology, which is suggested by Fare et al. (1989; 1993; 2004; 2005) and further developed through other researchers too (Tyteca, 1996; Zhou et al., 2008; Tone, 2001; 2004).

In DEA the DMUs that are efficient are defined by a rating of 1 (or 100%) and these ratings then form the efficiency frontier including the rest (not so efficient) DMUs; this rating provides a realistic and practical value of what a certain DMU has achieved and what can be further achieved by the other DMUs (Dostalova, 2014). Thus DEA disregards the ideal of efficiency according to the economic theory and focuses mostly on real and so far-from-ideal DMUs (Jablonský and Dlouhý, 2000).

With time, extensions and additions have been done to DEA modelling techniques. One of those that shows a good potential is Network DEA which accounts for the relative efficiency of a system, by taking into account its whole structure thus providing more informative and useful results (Kao, 2014).

DEA models are either input-oriented minimizing inputs or output-oriented models maximizing outputs without the use of more inputs (Seiford and Thrall, 1990). The relevant formulations of those two models are as follows (De Alencar Bezerra et al., 2017):

<u>Input-oriented</u>

Min θ_0

Subject to:

$$\theta_0 x_{i0} - \sum_{k=0}^{n} x_{ik}\lambda_k \geq 0.\forall i$$

$$-y_{j0} + \sum_{k=0}^{n} y_{jk}\lambda_k \geq 0.\forall j$$

$$\lambda_k \geq 0.\forall k$$

Output oriented

Max $(1/\theta_0)$

Subject to:

$$x_{i0} - \sum_{k=0}^{n} x_{ik}\lambda_k \geq 0. \forall i$$

$$-\frac{y_{j0}}{\theta_0} + \sum_{k=0}^{n} y_{jk}\lambda_k \geq 0. \forall j$$

$$\lambda_k \geq 0. \forall k$$

where θ_0 is DMU 0's efficiency score, λ_k is DMU k's contribution on the targets of DMU 0, y_{j0} is output j quantity for DMU 0, x_{i0} is output i quantity for DMU 0 and n is the quantity of DMUs used on the model. Moreover the decision variables are θ and λ.

Farrell's (1957) input measure operationalization of efficiency for multiple inputs /outputs assuming free disposability and convexity of the production set was introduced via linear programming estimators by Charnes et al. (1978). Therefore for a given DMU operating at a point (x, y) it can be defined as:

$$\hat{\Psi}_{DEA} = \left\{ (x, y) \in R_{+}^{p,q} \,\middle|\, y \leq \sum_{i=1}^{n} \gamma_i Y_i ; x \geq \sum_{i=1}^{n} \gamma_i X_i , \text{for } (\gamma_1, ..., \gamma_n) \right.$$
$$\left. \text{s.t.} \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \geq 0, i = 1, ..., n \right\}. \quad (1)$$

whereas x and y are the input and output vectors.

To estimate the frontier under the assumption of variable returns to scale (VRS) (Banker et al., 1984) input efficiency score of a DMU operating at a point under the assumption of VRS can be calculated as:

$$\hat{\theta}_{DEA}(x_0, y_0) = \inf\left\{\theta \middle| (\theta x_0, y_0) \in \hat{\Psi}_{DEA,VRS}\right\}$$

$$\hat{\theta}_{DEA}(x_0, y_0) = \min\left\{\theta \middle| y_0 \le \sum_{i=1}^{n} \gamma_i Y_i; \theta x_0 \ge \sum_{i=1}^{n} \gamma_i X_i, \theta > 0; \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \ge 0, i = 1, \dots, n\right\}. \quad (2)$$

Similarly the output efficiency score of a DMU operating at a point under the assumption of VRS can be calculated as:

$$\hat{\lambda}_{DEA}(x_0, y_0) = \sup\left\{\lambda \middle| (x_0, \lambda y_0) \in \hat{\Psi}_{DEA,VRS}\right\}$$

$$\hat{\lambda}_{DEA}(x_0, y_0) = \max\left\{\lambda \middle| \lambda y_0 \le \sum_{i=1}^{n} \gamma_i Y_i; x_0 \ge \sum_{i=1}^{n} \gamma_i X_i, \lambda > 0; \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \ge 0, i = 1, \dots, n\right\}. \quad (3)$$

DEA has been proven to have the following advantages (Vyas and Jha, 2017):

1. It considers the use of multiple inputs and outputs.
2. It is not required to use weights on inputs and outputs.
3. Efficiency is compared to the best operating unit rather an average performance.

At the same time the main drawback of DEA is that it creates a separate linear program for each DMU, which can be computationally exhaustive when the number of DMUs is large. Furthermore and to tackle some of the disadvantages of DEA, a recent study by Gavião et al. (2017), which proposed a combinatorial and probabilistic approach based on a hybrid model using LCA and DEA and with the use of a Probabilistic Composition of Preferences method (CPP), showed how it is possible to extend the discriminating power of DEA models.

3.1.2 Treating undesirable outputs in DEA

A common issue that has occurred in DEA is how to account for undesirable outputs in the production process. The current understanding is that researchers should praise DMUs for their provision of desirable or marketable outputs and penalise them for their provision of undesirable outputs (Yang and Pollitt, 2010). If inefficiency exists in the production, the undesirable pollutants should be reduced to improve the inefficiency and should be treated differently (Seiford and Zhu, 2001).

Many approaches have been put forward to account for this which are divided into direct and indirect ones; direct approaches refer to approaches that treat the undesirable output in its original form such as parametric output and input distance functions (Fare et al., 1993; Coggins and Swinton, 1996; Hailu and Veeman, 2001; Ho et al., 2017) and DEA methods (Skevas et al., 2012; Serra et al., 2014; Kabata, 2011; Yang et al., 2008; Skevas et al., 2014; Ramli et al., 2013).

On the other hand indirect approaches refer to treating the undesirable output as a classical input, whereas the undesirable output is moved to the input side of the model after some transformation and treated as one of the inputs (Mohd et al., 2015), as both inputs and undesirable outputs are the values that need to be minimised and therefore it is acceptable to treat both in the same manner. However, Seiford and Zhu (2001) highlighted that treating undesirable outputs as inputs will distort the actual production process since the relationship between inputs and outputs in the actual production process will be lost.

Researchers have focused on treating undesirable outputs, some of the most commonly cited works include: Fare et al (1989, 2000), Yaisawarng and Klein (1994), Lovell et al (1995), Fare and Grosskopf (1995, 2003, 2004), Thanassoulis (1995), Tyteca (1996), Rheinhard et al (1999, 2000), Scheel (2001), Hailu and Veeman (2001), Zofio and Prieto (2001), Dyckhoff and Allen (2001), Sun (2002), Seiford and Zhu (2002); Murtough et al. (2002), Kumar and Khanna (2002), Korhonen and Luptacik (2003), and Gomes (2003).

Dealing with undesirable outputs will ultimately affect DMUs' efficiencies. A production function shows strong disposability of undesirable outputs if these are freely disposable; whereas weak disposability links pollutants' reductions with lower production of desirable outputs, such as for instance CO_2 emissions which cannot be reduced using the existing available technologies (Halkos and Polemis, 2018).

The most common methods for treating undesirable outputs in DEA and the relevant production function are presented below.

3.1.2.1 Ignoring undesirable outputs

The first option to treat undesirable outputs is to simply disregard them from the production function. Ignoring the undesirable implies that they have no value in the final evaluation and may thus provide misleading results (Yang and Pollitt, 2009). Environmental undesirable outputs cannot be separated from the associated desirable output and a reduction in an undesirable output brings also a reduction in the relevant desirable outputs (Halkos and Polemis, 2018). Table 5 presents some studies that have ignored undesirable outputs from their analysis and the relevant outcomes.

Table 5: Examples of studies ignoring undesirable outputs

Hailu and Veeman (2001)	This paper assesses productivity improvement in the Canadian pulp and paper industry and found that conventional measures ignoring undesirable outputs underestimate true productivity growth.
Pathomsiri et al. (2008)	This paper assesses productivity of 56 US airports during the period 2000–2003 comparing their obtained results with those from models that do not include undesirable outputs.
Yang and Pollitt (2009)	The paper uses a sample of 582 base-load Chinese coal-fired power plants in 2002, showing that imposing the technically correct disposability features on undesirable outputs makes a significant difference to the final efficiency evaluation.
He et al. (2013)	This paper uses data from 50 enterprises in China’s iron and steel industry to evaluate their

	energy efficiency and productivity change and concluded that omitting undesirable outputs would result in biased efficiency change and technical change.

3.1.2.2 Treating undesirable outputs as inputs

Another option is to treat undesirable outputs as normal inputs in the production function. For example Korhonen and Luptacik (2004) measured the eco-efficiency of 24 coal-fired power plants in a European country and their modelling methods resembled those used in Tyteca (1996, 1997) who treated emissions directly as inputs in the sense that both inputs and undesirable outputs should be decreased.

In addition Reinhard et al. (2000) calculated the environmental efficiency for Dutch dairy farms in the presence of multiple environmentally damaging inputs and compared two methods of SFA and DEA. Furthermore this approach has been used for Canadian pulp and paper industry (Hailu and Veeman, 2001), Dutch sugar beet growers (De Koeijer et al. 2002) and greenhouse firms in the Netherlands (Lansink and Bezlepkin, 2003). The extent of Japanese banking inefficiency and the shadow price of problem loans were studied by Hirofumi and William (2008) in which case they modelled those loans as a jointly produced undesirable by-product of the loan production process. Yang and Michael (2010) stressed that these approaches inevitably assume undesirable outputs are strongly disposable.

Amirteimoori et al. (2006) extended the standard CCR (Charnes et al., 1978) model to a DEA like model dealing with the relative efficiency via increasing undesirable inputs and decreasing undesirable outputs. Also Jahanshahloo et al. (2005) presented an approach to treat both undesirable inputs and outputs at the same time in non-radial DEA models. More recently Farzipoor Saen (2010) proposed a model for supplier selection in the presence of both undesirable outputs and imprecise data. Table 6 presents some studies that have followed this approach.

Table 6: Examples of studies treating undesirable outputs as inputs

Reinhard et al. (2000)	This paper estimates comprehensive environmental efficiency measures for Dutch dairy farms, based on the nitrogen surplus, phosphate surplus and the total (direct and indirect) energy use of an unbalanced panel of dairy farm.
Lansink and Bezlepkin (2003)	This paper uses measures for the efficiency of greenhouse firms in the Netherlands over the period 1991–1995, using all possible inputs as well as single inputs like CO_2 and energy, indicating that firms using energy quite efficiently and are less efficient in terms of CO_2 emissions.
Korhonen and Luptacik (2004)	This paper measures eco-efficiency of 24 coal-fired power plants in which case they treated emissions as an input.
Gomes and Lins (2008)	In this case population, energy consumption, and GDP are modelled as outputs, and the undesirable output CO_2 emissions is modelled as input to assess the fair allocation of the carbon dioxide emission (undesirable output), contributing to the Kyoto Protocol and Carbon Market objectives.
Zhang et al. (2008)	This paper conducts an eco-efficiency analysis for regional industrial systems in China.

3.1.2.3 Treating the undesirable outputs in the non-linear model

A further approach simply treats the undesirable outputs as outputs in the production function. Fare et al. (1989) applied the nonparametric approach on a 1976 data set of 30 US mills which use pulp and three other inputs in order to produce paper and four pollutants, whereas they assumed weak disposability for undesirable outputs. Their results showed that depending on the use or not of undesirable outputs, the performance rankings of the DMUs were quite sensitive. Therefore traditional DEA models might show a biased indication of the current situation. Other studies present similar results (Pittman, 1983; Tyteca, 1996, 1997). All these studies employ a direct approach in which both desirable and undesirable outputs are treated in their actual format. In those cases it is assumed that desirable outputs are strongly disposable, while the undesirable outputs are assumed to be weakly disposable because their values cannot be augmented without affecting the values of other desirable outputs (Fare et al., 1989).

Chung et al. (1997) and Ball et al. (2004) extended the idea of Fare et al. (1989) and proposed the use of directional distance functions (DDF) to evaluate efficiency of DMUs when the production function also produces some undesirable outputs. In this approach the desirable outputs can be expanded and the desirable inputs and undesirable outputs can be reduced based on a given direction vector (Chung et al., 1997).

The directional output distance function which aims to increase the desirable outputs and decrease the undesirable ones and the inputs directionally, is defined as shown below:

$$\vec{D}(x, y, b; g) = \sup\{\rho: \left(x - \rho g_x, y + \rho g_y, b - \rho g_b\right) \in T\} \tag{4}$$

where inputs are represented as $x \in R_+^N$, good outputs as $y \in R_+^M$ and bad outputs as $b \in R_+^J$ and the non-zero vector g = -g_x, g_y, -g_b) determines the directions in which the inputs, desirable outputs and undesirable outputs are scales.

Many researchers have pointed that a DDF approach (suggested by Fare and Grosskopf, 2004) is the best solution as it allows for simultaneous increase in desirable outputs and reduction of undesirable outputs (Mohd et al., 2015). It helps avoid making a random choice between input and output technical efficiency measures by incorporating two sets of linear programmes, one of profit maximising and a second one in which technical efficiency is measured as a simultaneous reduction in the input vector and expansion of the output vector (Coelli et al., 2005).

Some examples of this use of undesirable outputs are presented in Table 7.

Table 7: Examples of studies treating the undesirable outputs in the non-linear model

Study / authors	**Approach**
Arcelus and Arocena (2005)	DDF approach to evaluate the efficiency of 14 OECD countries.
Picazo-Tadeo et al. (2005)	Environmental efficiency of Spanish producers of ceramic pavements using weak disposability and DDF.
Fare and Grosskopf (2010)	Slacks based DDF approach.
Fukuyama and Weber (2009)	Slacks-based DDF approach to study Japanese bank.
Fukuyama et al. (2011)	Evaluate three Japanese railway companies.
Choi et al. (2012)	A non-radial slacks-based measure to study the energy related CO_2 emissions in China.
Mahlberg and Sahoo (2011)	Radial and non-radial Luenberger productivity indicators.
Barros et al. (2012)	Utilised Russell DDF to evaluate Japanese banks.
Zhou et al. (2012)	Non-radial DDF to evaluate the electricity generation in OECD and non-OECD countries.
Zhang et al. (2013)	Meta-frontier non-radial DDF in order to study electricity generation in Korea.
Cheng and Zervopoulos (2014)	Generalized DDF approach to measure the efficiency of health care systems in 171 countries.
Chen et al. (2014)	Providing a comprehensive efficiency measurement to estimate the performances of OECD and non-OECD countries.
Chen et al. (2015)	Proposes an enhanced directional distance measure model for dealing with desirable and

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

	undesirable outputs while allowing some inputs and outputs to be zero through the assessment of CO_2 emissions in 111 countries.
Alfredsson et al. (2016)	This paper investigates the efficiency in the Swedish pulp and paper industry using national account data while using a directional distance function approach.
Lee et al. (2017)	Productivity measurement in the airline industry and examination of the determinants of productivity change.
Tamaki et al. (2019)	Efficiency measurement of public transport in world cities.

Moreover following those lines Haynes et al. (1993) measured the relative efficiency in pollution prevention activities. By assuming free disposability of all inputs and outputs they used chemicals and chemical residues as inputs and outputs along with traditional inputs and outputs and measured technical efficiency (Halkos and Tzeremes, 2009). Yaisawarng and Klein (1994) followed Fare et al. (1989) modelling strategy and examined the effect of SO_2 control on productivity change in US coal-fired power plants by imposing weak disposability on SO_2 emissions.

Lozano et al. (2013) put forward a DDF approach to deal with network DEA problems in which the processes may generate not only desirable outputs but also undesirable outputs. Kordrostami and Amirteimoori (2005) consider a multistage system and take into account the undesirable factors with a minus sign in the computation of the virtual inputs and virtual outputs of a multiplier formulation. Hua and Bian (2008) extend this approach to a more general network of processes.

There have been some objections to the weak disposability model such as those raised by Hailu and Veeman (2001) that “the weakly disposable approach leaves the impact of undesirable outputs on efficiency undetermined”, whereas Fare and Grosskopf (2003) responded that they disagree as the weakly disposable DEA model is consistent with physical laws and it allows the treatment of undesirable outputs showing the opportunity cost of reducing them.

Zhou et al. (2012) proposed a non-radial slacks-based measure (SBM) model extended with the incorporation of undesirable outputs. This model is an extension of Tone's (2001) original SBM model and uses a ratio approach to strike a balance between undesirable output reduction and desirable output increase. It combines environmental and economic inefficiencies and provides a composite index for modeling economic environmental performance. Skevas et al. (2012; 2014) used DDF approach to propose a risk adjusted DEA model to determine the efficiency of Dutch arable farmers in the presence of undesirable outputs.

Moreover Sueyoshi and Goto (2012a; b) introduced the concept of natural and managerial disposability in DEA analysis. Natural disposability shows that firms reduce their inputs in order to reduce their undesirable outputs, whereas managerial disposability shows that a firm increases its inputs in order to take advantage of the business opportunity after a change in environmental regulation. Finally Guo and Wu (2013) also treat the undesirable outputs as inputs, as from the perspective of profit, more undesirable outputs usually mean more inputs consumed and more costs.

3.1.2.4 Applying necessary transformations

Another approach is to apply a monotone decreasing transformation. Koopmans (1951) mentioned that some undesirable outputs like pollutant emissions and waste disposal affect negatively the environment and should be reduced. As such a first reaction is to apply some transformations as presented below:

a. (U)=−U; the so called ADD approach suggested by Koopmans (1951), in which case the undesirable inputs or outputs will become desirable. Though then some data may become negative and it is not straightforward to define efficiency scores for negative data.

b. (U)=−U + β is another option (Ali and Seiford, 1990; Scheel, 2001; Seiford and Zhu, 2001), but this classification may depend on β.

c. The multiplicative inverse: f (U) = 1/U (Golany and Roll, 1989; Lovell et al., 1995).

Related to ADD, there are several works dealing with negative data (but desirable) with directional distance functions, such as Fare and Grosskopf (2004), Silva Portela et al. (2004) and Yu

(2004). Those approaches are related to the weighted additive models so it is important to realise that the additive models are able to handle negative data (Seiford and Zhu, 2005).

In addition to the above mentioned approaches Cherchye et al. (2007) perform a transformation in the measurement scale based on a normalisation procedure, which can be applied both to desirable and undesirable outputs. This procedure provides indicators between 0 and 1. As data normalisation can lead to loss of information, this method is not commonly used in DEA studies (Zanella, 2004).

Halkos and Papageorgiou (2014) cover the gap in literature by providing a typical radial DEA model in three different settings in order to model regional environmental efficiency. More analytically based on Seiford and Zhu (2001, 2005) they use a linear transformation of bad output in order to model the pollutant as a regular output in a DEA formulation setting. Secondly it follows several other studies (Pittman 1981; Cropper and Oates 1992; Reinhard et al. 2000; Dyckhoff and Allen 2001; Hailu and Veeman 2001; Korhonen and Luptacik 2003; Mandal and Madheswaran 2010) treating the pollutant as a regular input. Finally the study uses the DEA formulation as proposed by Kuosmanen and Kortelainen (2005) and Kortlainen (2008) and the notion of eco-efficiency, therefore measuring regions' eco-efficiency levels in municipality waste generation. Table 8 presents relevant studies that have done this.

Table 8: Examples of studies applying necessary transformations to undesirable outputs

Adler and Golany (2001)	In this study deregulated airline networks are assessed in Western Europe.
Kortelainen (2008)	The environmental performance of 20 member states of the European Union in 1990–2003 is examined in this case study.
Amado et al. (2012)	This study uses DEA and transformation process to and the assess enhanced performance levels of businesses.
Halkos and Papageorgiou (2014)	This paper assess environmental efficiency of waste generation of 160 European regions in NUTS 2 level in seven

	European countries by applying the Seiford and Zhu methodology (2005)

3.1.2.5 New models

Recently some new models for treating undesirable outputs have come forward. Gomes and Lins (2008) propose a new approach to modelling undesirable outputs, based on the zero sum gains DEA models (ZSG-DEA). These models consider the production dependence among the DMUs (Gomes, 2003; Gomes et al, 2003, 2005; Lins et al, 2003) including as an additional restriction, the zero sum game property, in which whatever lost (or gained) by one of the players must be gained (or lost) by the others, that is the net sum of gains must be zero. This means that any DMU that wants to reach the efficient frontier by increasing the output (or decreasing the input) will make the others reduce (or increase) their values by this amount, in order not to change the total. In the case of pollutants, ZSGDEA models can be useful for the ecological economy (Sachs, 2000).

Huang et al. (2014) proposed a model named US-SBM which combines super efficiency, undesirable outputs and slacks-based measure (SBM) together. Fukuyama and Weber (2010) propose a slacks-based inefficiency measure for a two-stage system with bad outputs and analyse the source of inefficiency, which also does not consider the super efficiency.

Mohd et al. (2015) proposed an enhanced risk adjusted efficiency model based on the DDF DEA approach developed by Skevas et al. (2014) that also includes climatic variability and used interval data approach to represent uncertainty data will be developed, called “Risk Adjusted Interval DEA Model with Undesirable Outputs and Climatic Variability Conditions”.

Furthermore through using an environmental intensity index, the economy can expand without compromising the environment (Wursthorn et al. 2011). The general concept of Halkos et al. (2015) model is similar to Zaim’s (2004) who applied directional distance functions and constructed two indices. The first index is an economic one in which inputs are used to produce economic outputs while the second environmental index uses economic output to produce undesirable environmental outputs. The ratio of these two indices is used in order to acquire the pollution intensity index. Chen et al. (2012) also constructed a sustainability index consisting of 'industrial design module' and 'bio design module' in their study of sustainable product design in the automobile industry.

3.1.2.6 Evaluation of the different strategies to treat undesirable outputs

As described in the previous sections, researchers have widely focused on how they can treat undesirable outputs in DEA in order to take them into consideration in the production function. The methods presented above show that researchers are divided in their approaches and under different scenarios different techniques might seem more appropriate than others. The first approach of simply ignoring undesirable outputs is disregarded by most authors as it does not make sense to simply ignore those and pretend they don't exist.

The second approach of treating undesirable outputs as inputs has been widely used in research. Even so these perspectives have been criticised by academics (Hailu and Veeman, 2001; Fare and Grosskopf, 2003; Hailu, 2003). The central theme of this critique is the 'operationalization of weak disposability in empirical production analysis' (Kuosmanen, 2005). In those regards Kuosmanen (2005) pointed out that the common specification of weak disposability implicitly assumes that all DMUs in the sample apply a uniform abatement factor. Moreover Fare and Grosskopf (2003) mention some drawbacks but at the same time acknowledge that this approach is quite appealing and useful. The first is the free disposability assumption, since in reality unlimited increases in an undesirable output are not technically possible. Secondly when assessing power plants or energy sectors from a microeconomic perspective, the linkage between fuels, power and emissions should hold, as emphasised by Fare and Grosskopf (2005).

A further approach is treating those undesirable outputs as normal outputs in the production function. In those regards a direct approach is applied whereas both desirable and undesirable outputs are treated in their actual format. With the use of DDF it is possible to reduce the undesirable outputs based on a given direction vector (Chung et al., 1997). This type of DEA approaches has been widely used in environmental efficiency assessments (Arcelus and Arocena, 2015; Lozano and Gutierrez, 2008).

There have been some objections to the weak disposability model such as those raised by Hailu and Veeman (2001) that "the weakly disposable approach leaves the impact of undesirable outputs on efficiency undetermined", whereas Fare and Grosskopf (2003) responded that they disagree as the weakly disposable DEA model is consistent with physical laws and it allows the treatment of undesirable outputs showing the opportunity cost of reducing them.

Finally another option is to transform the undesirable outputs and several methods can be used to do this. By using the outputs' reciprocals another transformation is possible as suggested by Lovell et al. (1995). This approach has also been used by Ramanathan (2006) who used the reciprocal of the CO_2 outputs in his study. A further transformation has been proposed by Seiford and Zhu (2001, 2005) which assumes strong disposability for all the variables including the transformed undesirable outputs. Data translation has also been used by Lu and Lo (2007) in their study of regional development in China and by Wang et al. (2014) for the needs of their two-stage DEA model. New models have also been put forward recently in treating undesirable outputs. These have not been widely tested yet, so it is not possible to ascertain their value.

As it has come forward from the previous analysis the decision to use each method depends on the user and each analysis he/she intends to perform. There is no straightforward answer in which method to use as each one has its advantages and disadvantages. Therefore every researcher should consider first what he/she wants to achieve from their analysis.

3.1.3 Bias correction using bootstrap technique

Another important topic related to DEA is that of bias correction. Simar and Wilson (1998, 2000, 2002) stress that DEA estimators are shown to be biased by construction, thus they developed an approach based on bootstrap techniques to correct and estimate the bias of the DEA efficiency indicators. Bootstrap is based on the idea of simulating the data generating process (DGP) and applying the original estimator to copy the sampling distribution of the original estimator (Efron, 1979). In simple terms bootstrap involves randomly selecting thousands of 'pseudo samples' from the observed dataset (Coelli et al., 2005). It is an easy way to analyse the sensitivity of efficiency scores relative to the sampling variations of the estimated frontier (Simar and Wilson, 1998). Moreover bootstrap procedures produce confidence limits on the efficiencies of the units in order to capture the true efficient frontier within the specified interval (Dyson and Shale, 2010).

Then the bootstrap bias estimate for the original DEA estimator θ_{DEA} (x, y) can be calculated as:

$$\widehat{BIAS}_B(\hat{\theta}_{DEA}\,(x,y)) = B^{-1}\sum_{b=1}^{B}\hat{\theta}^{*}_{DEA,b\,(x,y)} - \hat{\theta}_{DEA\,(x,y)} \tag{5}$$

whereas B stands for bootstrap replications performed.

Then a biased corrected estimator of (x, y) can be calculated as:

$$\hat{\theta}_{DEA\,(x,y)} = \hat{\theta}_{DEA\,(x,y)} - \widehat{BIAS}_B\,(\hat{\theta}_{DEA\,(x,y)}) = 2\,\hat{\theta}_{DEA\,(x,y)} - B^{-1}\sum_{b=1}^{B}\hat{\theta}^{*}_{DEA,b\,(x,y)} \tag{6}$$

Finally, the (1−α) *x* 100 - percent bootstrap confidence intervals can be obtained for θ(*x*, *y*) as:

$$\frac{1}{\hat{\delta}_{DEA\,(X,Y)-\,nc^{*}_{1-a/2}}} \leq \theta\,(x,y) \leq \frac{1}{\hat{\delta}_{DEA\,(X,Y)-\,nc^{*}_{a/2}}} \tag{7}$$

3.1.4 Testing for the existence of constant or variable returns of scale

In DEA the use of CRS models requires the assumption of full proportionality between all inputs and outputs, though most often such proportionality cannot be assumed (Podinovski, 2004). This assumption is appropriate when firms operate at an optimal level (Coelli et al., 2005). One way to disregard such information is to use VRS.

It helps to estimate efficiencies without acknowledging whether an increase or decrease in input or outputs results in a proportional change in the outputs or inputs respectively (Cooper et al., 2011). This method includes both increasing and decreasing returns to scale. Charnes et al. (1978) were the first to propose the measurement of DMUs' efficiency under CRS, provided that all DMUs operate at their optimal level. Then Banker et al. (1984) employed VRS in their model, thus accounting for the use of technical and scale efficiencies in DEA. Table 9 presents the main differences between CRS and VRS.

Table 9: Differences between VRS and CRS in DEA

VRS	CRS
No proportional change for input variables (Reddy, 2015).	Proportional change for input and output variables.
Based on increasing or decreasing returns to scale (Tsai and Mar Molinero, 2002).	Based on constant input or output variable.
Based on model described by Banker, Charnes and Cooper.	Based on model described by Charnes, Cooper and Rhodes.

To test this approach and following Simar and Wilson (2002) bootstrap approach we compare between CRS and VRS according to these hypotheses: $H_o : \Psi^{\theta}$ is globally CRS against $H_1 : \Psi^{\theta}$ is VRS. The test statistic mean of the ratios of the efficiency scores is then provided by:

$$T\ (X_n) = \frac{1}{n} \sum_{i=1}^{n} \frac{\widehat{\theta}_{CRS,n}\ (X_I,Y_i\ )}{\widehat{\theta}_{VRS,n}\ (X_I,Y_i\ )} \qquad (8)$$

Then the *p-value* of the null-hypothesis can be obtained:

$$p - value = prob\ (T\ (X_n) \leq T_{obs}\ ]\ H_0\ is\ true) \qquad (9)$$

where T_{obs} is the value of T computed on the original observed sample X_n and B is the number of bootstrap reputations. Then the *p-value* can be approximated by the proportion of bootstrap values of T^{*b} less the original observed value of T_{obs} such as:

$$p - value\ \approx\ \sum_{b=1}^{B} \frac{\mathrm{I}\ (T^{*b} \leq T_{obs})}{B} \qquad (10)$$

In the case of CRS or CCR model, the efficiency frontier is a straight line crossing the point of origin and the best performers (efficient DMUs) (Banker et al., 1984). Figure 41 presents the graphical representation of the efficient and inefficient DMUs along the frontier, in which case DMU_2 is the best performer and is used as a reference for all other DMUs. In those regards further improvement of efficiency scores for inefficient DMUs can be achieved through the implementation of good practices of the efficient ones (Laso et al., 2018).

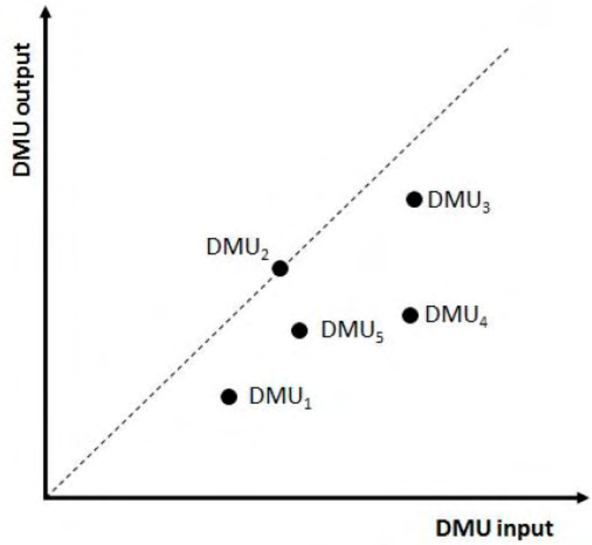


Figure 41: Graphical representation of the efficiency frontier of CCR model (Vlontzos et al., 2017)

3.1.5 DEA in use: MSW management studies

The first application of DEA in this Thesis has to do with waste management. A few studies recently have also used DEA to evaluate the efficiency of waste management (Bosch et al., 2000; Worthington and Dollery, 2001; Moore et al., 2005; Marques and Simões, 2009; Simões et al., 2010; Benito et al., 2010; Chen et al., 2010; De Jaeger et al., 2011; Chen and Chen, 2012;). Further modifications are being made to DEA so that it can better capture the full complexity of the process, for instance Rogge and De Jaeger (2012; 2013) suggested a way to differentiate performance efficiency by the main municipal solid waste components. Some regulating bodies and governments are using DEA also in their waste management policies, such as Spain and Australia (Simões et al., 2010).

DEA can be used in waste management studies, in order to assess the efficiency of the waste collection programs that are inefficient and need to be improved for instance through studying the collection methods, transportation ways, collection vehicles, and collection times of the waste collection programs of the efficient DMUs (Yüksel, 2012). One study conducted in the Flemish municipalities aimed at those activities where the municipality under-performed and therefore cost efficiency gains are possible; results prove that the average cost efficiency score is quite low for those waste fractions which have the lower cost share, hence it is obvious that the municipalities focus those activities that have the biggest cost share such as residual MSW collection and processing services (Rogge and De Jaeger, 2012). In another study conducted in large cities in Turkey, the efficiency of waste collection programs in those cities was benchmarked and it was found that apart from two cities the rest could improve their outputs (Yüksel, 2012).

Moreover research conducted in Spain found that per capita income and population density can explain differences in regional efficiencies (Exposito and Velasco, 2018). In these regards for instance one basic application is the amount of waste that can be reduced without worsening any input or output (Cooper et al., 2011), as it requires only minimal information and assumptions, but also because other types assume that technical efficiency has been achieved (Førsund and Sarafoglou, 2005). Most waste-related studies which employ DEA focus on waste or pollution as an undesirable output (Scheel, 2001; Seiford and Zhu, 2002).

DEA has been also applied to measure the environmental performance at both micro and macro levels: measurement of companies' ecological efficiency (Dyckhoff and Allen, 2001); environmentally conscious manufacturing programs (Sarkis, 1999; Zaim, 2004; Sueyoshi and Goto, 2014); investment into waste treatment technologies (Sarkis and Weinrach, 2001); waste prevention versus ecological treatment and recycling (Sarkis and Cordeiro, 2001); carbon dioxide emissions on a national level (Ramanathan, 2002, 2005; Kumar, 2006; Wang et al., 2012).

In more detail regarding previous DEA works, Bosch et al. (2000) assessed MSW collection services in Spain by using as inputs containers, vehicles and workers and as output waste collected. The same output was used by Benito et al. (2010) and municipal solid waste management (MSWM) costs as input again in Spain. Similarly waste treated and waste recycled were used as outputs and MSWM costs as inputs for Czech Republic (Fiala, 2007) and Portugal (Marques and Simoes, 2009).

Worthington and Dollery (2001) studied solid waste management by local governments, including municipalities taking into account as input collection and expenditures and as output garbage and recyclables collected. MSWM costs were used as inputs in further studies as well, for instance De Jaeger et al. (2011) with a focus on Belgium and Simoes et al. (2010) on Portugal. Moore et al. (2005) examined municipal waste management using as inputs staff and MSWM budget and as output citizens served in the 46 US largest cities. Finally Huang et al. (2011) studied local MSW collection services in Taiwan using a dummy input and five key performance indicators (KPIs) as outputs.

As is evident from the studies mentioned above DEA has been widely used in assessing waste management practices and has proved to be a valuable tool for researchers and policy makers likewise.

In those regards, the concept of technical efficiency, for instance one basic application is the amount of waste that can be reduced without worsening any input or output (Cooper et al., 2011), as it requires only minimal information and assumptions, but also because other types assume that technical efficiency has been achieved (Førsund and Sarafoglou, 2005). Most waste-related studies which employ DEA simply focus on waste or pollution as an undesirable output within the standard DEA framework (Scheel, 2001; Seiford and Zhu, 2002). DEA has been also applied to measure the environmental performance at both micro and macro levels (Kortelainen and Kuosmanen, 2005; frameworks by Sarkis, 1999; Zaim, 2004; chemical and pharmaceutical firms in Sueyoshi and Goto, 2014):

- investment into waste treatment technologies (Sarkis and Weinrach, 2001),
- waste prevention versus ecological treatment and recycling (Sarkis and Cordeiro, 2001),
- carbon dioxide emissions on a national level (Ramanathan, 2002; 2005; Kumar,2006; Wang et al., 2012).

3.1.6 DEA in use: energy efficiency studies

A lot of research has been conducted in the field of energy and environmental efficiency with the use of DEA. Mardani et al. (2017) and Sueyoshi et al. (2017) have composed a list of the main studies working on this topic. Mardani et al. (2017) identified a total of 144 papers between 2006 and 2015, the specific focus of those studies can be seen in Table 10.

Table 10: Distribution papers based on application areas (Mardani et al., 2017)

Application fields	Number of papers	Percentage (%)
Environmental efficiency	23	15.97
Economic and eco-efficiency	14	9.72
Energy efficiency	35	24.31
Renewable and sustainable energy	23	15.97
Water efficiency	4	2.78
Energy performance	8	5.56
Energy saving	6	4.17
Integrated energy efficiency	6	4.17
Other application areas	25	17.36
Total	144	100

Sueyoshi et al. (2017) present DEA applications from 1980 to 2010 (693 studies) and a considerable increase in research has been noticed after 2000. The first research work on energy efficiency was by Färe et al. (1983). Further studies focused both on developed (Hailu and Veeman, 2001; Mukherjee, 2008, Zhou et al., 2007, Halkos and Tzeremes, 2009) and developing countries (Lee et al., 2002; Mukherjee, 2010).

These studies have focused on different aspects of energy efficiency. For instance Zhou et al. (2008) by using DEA measured the carbon emissions' performance of eight regions worldwide in 2002, while they examined the environmental efficiency of 26 OECD countries from 1995 to 1997 (Zhou et al., 2007). Halkos and Tzeremes (2013a) examine energy consumption on countries' economic efficiency levels and DEA in that case presents economic efficiency variations among the examined countries. Additionally the effects of renewable energy on the technical efficiency of 45 economies during 2001-2002 is studied by Chen and Hu (2007) showing that increasing the use of renewable energy improves an economy's technical efficiency.

Chen et al. (2010) evaluate the performance-based efficiencies of 19 largescale municipal incinerators in Taiwan with different operational conditions for 2002-2005, leading to optimal management strategies for promoting the quality of solid waste incineration. Moreover the renewable energy sector in Greece is examined through DEA for 78 firms for 2006-2008 showing that the majority of the firms operating in the Greek renewable sector are based on the production of wind energy (Halkos and Tzeremes, 2012).

Hu and Wang (2006) measure the energy efficiency of 29 regions in China and propose a total factor energy efficiency evaluation method. The technical efficiency of energy utilities in China and Taiwan is also studied by Yeh et al. (2010). The same approach but with the incorporation of environmental efficiency as well is followed by Bian and Yang (2010). Furthermore Zhou and Ang (2008) measure energy efficiency using both energy and non-energy inputs.

Wang et al. (2012) create a mixed efficiency model which includes both economic and environmental efficiency attempting to proportionally increase desirable outputs and decrease undesirable outputs. Wang et al. (2013) evaluate energy and environmental efficiency of 29 regions in China with an improved DEA model. Finally Song et al. (2018) developed an improved method by which to evaluate resource and environmental efficiency with the evaluation of resource inputs into the objective function and focus on resource inputs, undesirable outputs and desirable outputs simultaneously.

3.2 Panel data and proposed econometric methods

Apart from DEA as presented in Section 3.1, Section 3.2.1 introduces the econometric methods that will be used and then Section 3.2.2 presents examples of studies using panel data in relation to MSW. Finally Section 3.2.3 presents the main points around Environmental Kuznets Curve (EKC) which will also be examined.

3.2.1 Econometric methods

Panel data (also known as longitudinal or cross-sectional time-series data) constitute a dataset in which the behaviour of individual entities is observed across time (entities may be for instance countries, individuals, companies) (Torres-Reyna, 2007; Hsiao, 2003; Hsiao, 2007). In the present part of the Thesis, MSW is analysed under the OECD framework and its relationship to the education level is evaluated. To ascertain the relationship between MSW/capita (MSW/c) and GDP/capita (GDP/c), Box-Cox specifications have been used testing linearity against logarithmic forms. The following proposed model specification is constructed:

$$(MSW/c)_{it} = \beta_0+\alpha_i+\gamma_t+\beta_1(GDP/c)_{it}+\beta_2(GDP/c)^2_{it}+\beta_3(GDP/c)^3_{it}+\beta_4 Educ + \varepsilon_{it} \qquad (11)$$

where MSW/c is the municipal solid waste per capita, GDP/c is Gross Domestic Product per capita, Educ refers to the education level. Countries are indexed by i and time by t while α_i's corresponds to country specific and γ_t's to time specific intercepts. Finally, ε_{it} is the stochastic error term with the usual properties.

Panel data methods have been applied in estimating the above specification. First, fixed effects (FE) are applied permitting each separate country to have a different intercept and by treating α_i and γ_t as regression parameters (Halkos, 2011a). Secondly the random effects (RE) are applied where individual effects are treated as random and α_i and γ_t are considered as components of the random disturbances (Torres-Reyna, 2007). A Hausman (1978) test is performed for inconsistency in the RE estimate. The advantages of the RE are (Hsiao, 2007):

a) The number of parameters stays constant when sample size increases.

b) It allows the derivation of efficient estimators that make use of both within and between (group) variation.

c) It allows the estimation of the impact of time-invariant variables.

The advantages of FE are that it can allow the individual and/or time specific effects to be correlated. Neither does it require an investigator to model their correlation patterns. The disadvantages of the FE specification are (Neyman and Scott, 1948):

a) The number of unknown parameters increases with the number of sample observations. In the case when T (or N) is finite, it introduces the classical incidental parameter problem.

b) The FE estimator does not allow the estimation of the coefficients that are time-invariant.

Additionally, the proposed Generalized Method of Moments (GMM) in the dynamic specifications minimizes the following expression regarding β

$$M(\beta)=\left(\sum_{i=1}^{N}\Psi_i' u_i(\beta)\right)W\left(\sum_{i=1}^{N}\Psi_i' u_i(\beta)\right)=\zeta(\beta)' W\zeta(\beta) \qquad (12)$$

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

where W is a pxp weighting matrix, Ψ_i is a $T_i xp$ instruments matrix for cross section i and $u_i(\beta)=(Y_i - f(X_{it},\beta))$. The weighting of matrix W is calculated using the White robust covariances the coefficient covariance estimates are given as:

$$\left(\frac{M^*}{M^*-k^*}\right)\left(\sum_t X_t' X_t\right)^{-1}\left(\sum_t X_t' \hat{u}_t \hat{u}_t' X_t\right)\left(\sum_t X_t' X_t\right)^{-1} \qquad (13)$$

where M^* is the total number of stacked observations and k^* the number of estimated parameters. Orthogonal deviations as proposed by Arellano and Bond (1988) state each observation as deviation from the average of future observations in the sample and weigh each deviation to standardize the variance:

$$x_{it}^* = \left[x_{it} - (x_{i(t+1)}+...+x_{iT})/(T-t)\right]\sqrt{(T-t)}/\sqrt{T-t+1} \quad \text{t=1,...T-1} \qquad (14)$$

The (T_i–q) equations for individual unit *i* can be written as:

$$Y_i = \delta w_i + d_i \eta_i + v_i \qquad (15)$$

with δ a parameter vector including α_κ's, β's and λ' s; and w_i is a data matrix containing the time series of the lagged endogenous variables, the x' s, and the time dummies and d_i is a (T_i-q) x1 vector of ones.

One difficulty that is usual when working with panel data is the possibility that variables or random disturbances are correlated across the panel dimension (Bollen and Brand, 2011). For this reason cross-sectional dependence is tested using the Pesaran’s (2004) cross-sectional dependence (CD) test to assess if the time series in the panel dataset are cross-sectional independent. If not, Ordinary Least Squares (OLS) Dummy estimator allowing for individual fixed effects with Driscoll-Kraay standard errors are used to correct the variance-covariance matrix in cases of serial and spatial correlation after testing for cross-sectional dependence. According to Pesaran (2004) the necessity of unit root tests taking into consideration errors cross-section dependence are required. Additionally and in the case of using REs robust standard errors are demanded after applying a Breusch-Pagan test for individual effects.

In case of CD unit roots are tested using robust tests. Thus the typical Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests are extended in panel data analysis with the main issue of homogeneity in the autoregressive parameter (Dickey and Fuller, 1981). The proposed tests by Levin et al. (2002), Harris and Tzavalis (1999), Hadri (2000), Breitung (2000) and Breitung and Das (2005) presume homogeneity for the autoregressive parameter and demand strongly balanced panels. Im et al. (2003) and Fisher (1932) type tests relax this restrictive assumption and even more they do not necessitate strongly balanced panels.

In terms of the asymptotic behavior of the unit root tests both of the time series, T, and the cross section N dimensions then when $N \to \infty$ and $T \to \infty$ Levin et al. (2002) and Fisher (1932) type tests may be used although for the latter the number of panels not having a unit root must raise at the same rate as N. In the tests proposed by Hadri (2000), Breitung (2000) and Breitung and Das (2005) first T tends to infinity for fixed N and subsequently N tends to infinity. But in *Fisher type* tests N is fixed making these tests consistent against the alternative of one panel being stationary. Harris and Tzavalis (1999) and Im et al. (2003) tests are asymptotically normal for $N \to \infty$ and fixed T. Exception is the t-bar statistic of Im et al. (2003) test where N may also be presumed fixed with no gaps in the data.

Similarly, panel co-integration tests are performed using tests based on Westerlund (2007) and Pedroni (1999; 2000; 2004). The Westerlund test checks for co-integration based on the significance of the error correction term in the error correction model with the null hypothesis of no error correction and acceptance implying no co-integration (Westerlund, 2007). Specifically four panel cointegration tests as proposed by Westerlund (2007) are used. The G_t and G_a statistics test the null hypothesis of no-cointegration of all cross sectional units (rejection implies cointegration for at least one unit) and the P_t and P_a statistics testing the null hypothesis of no cointegration for all cross sectional units with rejection implying cointegration for the panel in total. Pedroni's (1999; 2000; 2004) cointegration tests suggest seven test statistics for the null of no-cointegration, with four panel statistics and three group statistics test for testing either panel co-integration or cointegration across cross-sections.

3.2.2 Panel data in MSW studies

The first published paper on panel data analysis was that of Balestra and Nerlove (1966). Following that one, of the first to study panel data was Hsiao (1986) who found there were only 29 studies focusing on panel data at that time. This number increased to 687 by 2004 and 773 by 2005 (Hsiao, 2007). This increase of research using panel data is mainly due to the increase of available data, the more sophisticated modelling techniques and the challenging methodology (Hsiao, 2007).

Some recent research conducted in the field of panel data and MSW is presented below. To start with Johnstone and Labonne (2004) use a panel dataset of MSW in OECD countries to show the economic and demographic determinants of generation rates of MSW over consumption expenditures, urbanisation and population density. Two disaggregated panel datasets on Italian Regions and Provinces (1996-2004 data for the 20 regions, 2000-2004 data for 103 provinces) are used to estimate the extent to which delinking between waste production and economic drivers is actually occurring (Mazzanti et al., 2005).

The main trends of MSW generation, disposal and recycling are studied by Karousakis (2006) using a panel data of 30 OECD countries over a period of 30 years. Tsai (2008) uses Taiwan as a case study to estimate the impact of social capital on the regional recycling rate. Waste generation, incineration and landfill dynamics are assessed through panel data for 25 EU countries to examine the effects of different drivers and potential differences among Western and Eastern EU countries (Mazzanti and Zoboli, 2009). Prefecture-level panel data on illegal dumping in Japan from 1996 to 2005 are studied by Ichinose and Yamamoto (2011).

Moreover the long-term effect of unit-based pricing on waste generation and recycling is studied by Usui and Takeuchi (2014) using panel data for 665 Japanese cities over the course of 8 years. The potential impact of economic and political factors on the provision of waste management services is studied through panel data for 2002-2010 by Plata-Diaz et al. (2014). Policy effectiveness from an EKC test in China is examined through panel data analysis by Wu et al. (2015).

Furthermore Lakhan (2016) uses panel data collected from 223 Ontario municipalities for years 2003-2014 along with semi structured interviews with recycling stakeholders to examine whether municipalities respond to financial incentivization by increasing total recycling or decreasing costs. Han and Zhang (2017) use panel data for 1998-2012 to assess the impact on MSW per capita when employing the source separation method. Finally Droste et al. (2017) employ an econometric analysis of panel data for two decades to estimate the correlation of the introduction of ecological fiscal transfers in Brazilian states with protected area coverage.

3.2.3 Environmental Kuznets Curve (EKC) and MSW studies

Kuznets (1955) hypothesized an inverted-U shape for the relationship between a measure of inequality in the distribution and the level of income. Because of its similarities to the pattern of income inequality described by Kuznets, the environmental pattern is called an Environmental Kuznets Curve (EKC) (Halkos, 2003). The EKC presents a hypothesised relationship between chosen indicators of environmental degradation and income per capita (Stern, 2003). It suggests that despite environmental pollution initially increases with GDP per capita at some point GDP and emissions become decoupled, thus further increases in GDP are then associated with decreases in environmental pollution as production and treatment technologies improve with national incomes (Kinnaman, 2009).

The existing empirical evidence suggest that EKCs occur for pollutants with semi-local and medium-term impacts (Arrow et al., 1995; Cole et al., 1997; Ansuategi et al., 1998; Halkos, 2003). The use and study of EKCs goes back at least 25 years. Grossman and Krueger (1991) produced the first EKC study on the potential environmental impacts of NAFTA. They estimated EKCs for SO_2, dark matter (fine smoke) and suspended particles (SPM). While Shafik and Bandyopadhyay's (1992) study was influential as the results were used in the 1992 World Development Report, they estimated EKCs for ten different indicators using three different functional forms; their results show that lack of clean water and lack of urban sanitation declined uniformly with increasing income and over time.

In the case of MSW and as the income increases advances in technology regarding recycling and green design are present as well (Mazzanti and Zoboli, 2009). In more detail, in the early stages of economic growth, degradation and pollution increase, but beyond a certain level of income per capita (which will vary for different indicators) the trend reverses, so that at high-income levels economic growth leads to environmental improvement, thus the result is an inverted U-shaped function of income per capita (Stern, 2003; Stern et al., 1996), as presented in Figure 42.

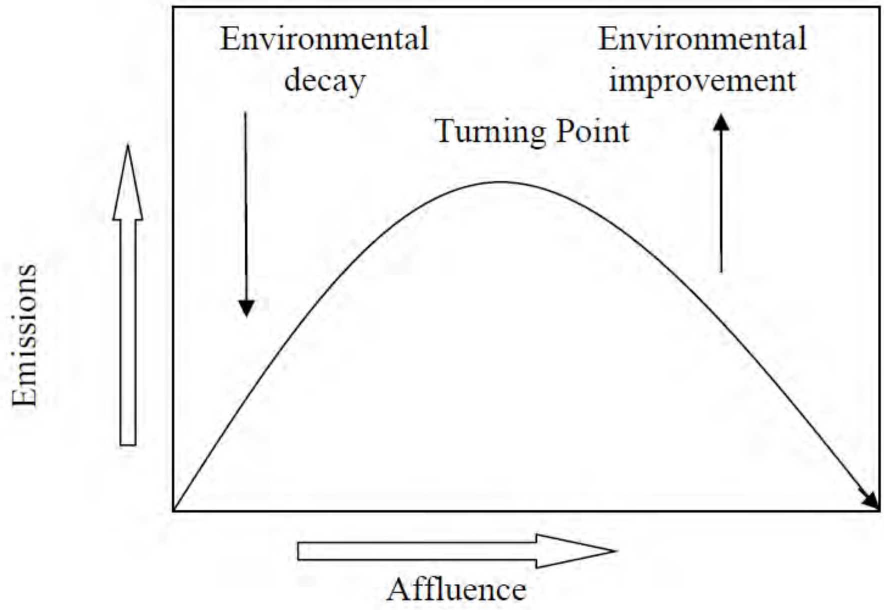


Figure 42: The Environmental Kuznets Curve (Khajuria et al., 2010)

MSW quantities are expected to decrease with the increase of income at income levels exceeding three times their current levels (Kinnaman, 2009). There are few EKC analyses on waste and material flows. No evidence of U-shape EKC curve was identified by Cole et al. (1997). On the other hand, Leigh (2004) provides evidence for EKC regarding a waste/consumption indicator deriving from the environmental sustainability indexes. Generally it is noticed that strict EKC evidence has been rare, but most researchers support the opinion that waste indicators tend to increase with income or other economic drivers (Mazzanti and Zoboli, 2005a). Table 11 provides a summary of empirical studies which have examined the relationship between MSW and income.

Table 11: Summary of empirical studies regarding relationship between MSW and income (adapted from Gnonlonfin et al., 2017)

Study	Sample	Estimator	Income indicator	Income effect	Turning Point
Within country level					
Lim (1997)	South Korea	Time series	GDP/capita	Positive	n.a.
Song et al. (2008)	29 Chinese province (1985-2005)	Panel	GDP/capita (real yuan 2000)	Positive	31,668
Mazzanti et al. (2009a)	Italian regions (1996-2005)	Panel	GDP/capita (Euro)	Positive	-
Mazzanti et al. (2009b)	Italian cities (2000-2004)	Panel	Value added/capital (const. Euro 2000)	Positive	22,8-25,9
Ichinose et al. (2011)	Japanese municipalities	Cross-section	Taxable income (million yen)	Positive	4.25
Khajiuria et al. (2012)	India (1947-2004)	Time series	Gross domestic saving (% GDP)	Positive	26.7%
Cross-country level					
Shafik and Bandyopadhyay (1992)	39 countries (1985)	Cross-section	GDP/capita ($ ppa)	Positive	-
Shafik (1994)	39 countries (1985)	Cross-section	GDP/capita ($ ppa)	Positive	-
Cole et al. (1997)	13 countries OECD (1975-1990)	Panel	GDP/capita ($ ppa)	Positive	-
Iafolla et al. (2010)	EU 15 (1997-2007)	Panel	Household final consumption spending/capita (Euro)	Positive	-
Mazzanti and Zoboli (2009)	EU 25 (1995-2005)	Panel	Household final consumption spending/capita (Euro 1995)	Positive	-

3.3 Data used in this Thesis

In the present Thesis DEA analysis was used in relation to waste management through four different aspects, first MSW data was assessed regarding both EU regions (Section 3.3.1) and EU countries (Section 3.3.2), then cultural dimensions and MSW data were analysed (Section 3.3.3) and energy and MSW related data have been taken into account as well (Section 3.3.4). Finally Section 3.3.5 shows the data for the OECD panel analysis which was performed with econometric methods.

3.3.1 EU regional data (focus MSW efficiency)

First regional EU data (NUTS level 2) was evaluated for 172 regions from 17 countries and for the years 2009, 2011 and 2013. According to the 1961 Brussels Conference on Regional Economies, NUTS 2 regional classification [1] is the most common framework used by Member States to apply their regional policies and therefore is the most appropriate level for analysing regional environmental problems (Eurostat, 2007). The parameters used, are counted as presented below:

- Regional Gross Domestic product (GDP): current prices (million €)
- Regional waste arisings: waste generated (thousand tonnes)
- Regional employment rate: thousand number of people
- Regional gross fixed capital formation (capital investment): current prices (million €)
- Regional population density: persons per km^2

In more detail regarding each country, Table 12 presents the number of regions examined in this Thesis.

Table 12: Regions examined divided by country

Belgium	11	**Bulgaria**	6
Czech Republic	9	**Germany**	36
Estonia	1	**Italy**	21
Latvia	1	**Lithuania**	1
Luxembourg	1	**Hungary**	6
Malta	1	**Netherlands**	12

[1] Further information on NUTS classification : http://ec.europa.eu/eurostat/web/nuts/overview

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Austria	7	**Poland**	16
Portugal	7	**Slovakia**	4
UK 33			

Table 13 presents the descriptive statistics of the inputs and outputs used in the different DEA model formulations and for all the years in question for the 172 regions.

Table 13: Descriptive statistics for all years and regions

	GDP (million €)	Waste (thousand tonnes)	Employment rate (thousand)	Capital investment (million €)	Population density (persons per km2)
2009					
Mean	44,368.44	847.95	81.13	8,937.98	387.05
St. dev	49,191.21	672.81	58.43	9,941.54	758.27
Min	2,816.00	79.37	3.00	455.06	11.40
Max	347,444.00	4,925.13	291.50	74,342.44	6,702.10
2011					
Mean	48,075.32	827.83	76.03	9,645.91	389.68
St. dev	52,355.63	662.81	55.53	10,506.05	778.63
Min	2,948.00	78.42	2.7	428.36	11.50
Max	367,536.00	4,824.17	266.70	74,588.87	7,131.10
2013					
Mean	49,583.85	801.78	72.58	9,405.29	393.90
St. dev	52,647.66	632.13	54.61	9,834.63	796.81
Min	2,951.00	72.59	2.5	501.18	11.50
Max	362,494.00	4,594.69	264.00	66,607.77	7,324.40

3.3.2 EU country data (focus MSW efficiency)

In the second DEA application the following variables are used: waste, GDP, labour, capital (investment), population density,), SOx emissions (from waste), NOx emissions (from waste) and GHG

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

emissions (from waste) with data obtained from Eurostat[2]. In total 28 EU Member States are studied for the years 2008, 2010, 2012 and 2014. The parameters are counted in the following units for this analysis:

- Waste: waste generated by households (tonnes)
- GDP: current prices (million €)
- Labour: number of people (in thousand)
- Gross fixed capital formation (investment): current prices (million €)
- Population density: persons per km^2
- SOx emissions: tonnes from waste sector
- NOx emissions: tonnes from waste sector
- GHG emissions: million tonnes of CO_2 equivalent.

Following the collection of all the relevant data from Eurostat, Table 14 presents the descriptive statistics of the inputs and outputs used in the different DEA model formulations and for all the years in question.[3]

Table 14: Descriptive statistics for all years and countries

	Waste (tonnes)	GDP (millon €)	Labor (thousand)	Investment (million €)	Population density (persons per km²)	SOx emissions from waste (tonnnes)	NOx emissions from waste (tonnes)	GHG emissions from waste (million tonnes)
2008								
Mean	7,921,692.5	433,181.5	7,986.4	106,864.2	167.5	143.5	403.9	6.6
St. dev	11,152,434.5	660,359.2	10,180.0	147,510.1	244.3	312.1	717.1	9.3
Min	145,817.0	5,468.5	158.6	1,203.1	15.6	0.0	0.0	0.0

[2] Data used for Norway's capital and GDP for 2014 are the same as 2012 due to lack of data from Eurostat for that year.
[3] The empirical results were derived using MaxDEA.

Max	35,754,996.0	2,407,913.0	38,541.5	520,809.0	1,295.5	1,362.0	2,707.0	41.1
2010								
Mean	7,950,260.5	422,196.1	7,774.2	94,052.4	169.2	92.3	385.7	6.0
St. dev	10,880,325.9	645,277.5	10,076.9	136,172.4	247.5	201.1	673.4	7.7
Min	149,564.0	5,541.5	162.6	1,411.6	16.0	0.0	0.0	0.0
Max	36,311,611.0	2,375,659.2	38,737.8	501,449.0	1,311.7	890.0	2,433.0	29.9
2012								
Mean	7,666,294.2	427,893.0	7,743.8	97,806.3	170.5	91.9	399.3	5.6
St. dev	10,571,666.9	658,959.0	10,134.9	144,453.6	250.7	191.3	675.2	7.0
Min	155,147.0	5,680.2	170.3	1,306.0	16.5	0.0	0.0	0.0
Max	36,471,810.0	2,471,753.3	39,126.5	555,866.0	1,327.4	825.0	2,355.0	24.8
2014								
Mean	7,491,376.3	2,055,588.6	8,535.6	99,952.0	173.0	104.7	392.8	5.2
St. dev	10,481,346.3	6,105,822.7	11,040.4	149,253.3	259.3	232.7	647.3	6.1
Min	154,456.0	8,467.1	189.0	1,465.4	16.9	0.0	0.0	0.0
Max	36,887,634.0	32,591,713.0	40,990.0	586,555.0	1,375.2	923.0	2,193.0	19.5

3.3.3 Cultural dimesnions data and EU country data (focus MSW efficiency and waste culture)

In the third DEA application the following variables are used: waste, GDP, labour, capital, population density with data obtained from Eurostat[4]. In total 22 EU Member States are studied for the years 2005, 2010 and 2015. The parameters are counted in the following units for this analysis:

[4] In cases where data was not available for a variable for the specific years chosen, the data from the previous year was used.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

- Waste: waste generated by households (tonnes)
- GDP: current prices (million €)
- Labour: number of people (in thousand)
- Gross fixed capital formation: current prices (million €)
- Population density: persons per km^2

Following the DEA analysis, the efficiency scores are contrasted to Hofstede's cultural dimensions, which include as already mentioned: Power distance index, Invidualism vs Collectivism, Masculinity vs Feminity, Uncertainty Avoidance index, Long term vs short term orientation and Indulgence versus Restraint. Moreover they are contrasted to Schwartz's cultural dimensions which are comprised of: Harmony, Conservatism, Hierarchy, Mastery, Affective autonomy, Intellectual autonomy and Egalitarianism. According to Hofstede (1983) individualism is positively related to economic development and some of the psychological features that define modern society, such as low integration of relatives, independence and future orientation, etc. (Yang, 1988). In this analysis it is assumed that cultural dimensions' data do not change over this examined period as it takes a longer time for a change of behaviour to be established.

The efficiency scores obtained through the DEA analysis as described above have then been analysed in comparison to Hofstede's and Schwartz's cultural dimensions. This has been done on STATA with the use of multiple regression models. Multiple regression is used to predict the value of a dependent variable based on the value of two or more independent variables. Therefore, regression analysis is a mathematical and statistical tool used to sort out which of the independent variables in question do have an impact on the dependent variable (Gallo, 2015). The regression model that is formed, is as follows:

$$y(efficiency\ score) = f(cultural\ indexes)$$

The below main assumptions need to be accounted for before using linear regression models (Nau, 2018):

a. Linearity and additivity of the relationship between the variables: (1) the expected value of the dependent variable is a straight-line function of each independent variable, (2) the slope of that line does not depend on the values of the other variables and (3) the effects of different independent variables on the expected value of the dependent variable are additive.

b. Statistical independence of the errors (in particular, no correlation between consecutive errors in the case of time series data)

c. Homoscedasticity (constant variance) of the errors: (1) versus time (in the case of time series data), (2) versus the predictions, (3) versus any independent variable and (4) normality of the error distribution.

Some of the main outputs that are taken into account in the regression output are (The Trustees of Princeton University, 2007):

1. R^2: it's the proportion of the variance in the dependent variable explained by the independent variables, though it does not reflect the extent to which any particular independent variable is associated with the dependent variable.

2. The standard error: is an estimate of the standard deviation of the coefficient showing the amount it varies across cases. If a coefficient is large compared to its standard error, then it is probably different from 0.

3. The coefficient: its size provides the size of the effect that variable is having on the dependent variable and the sign on the coefficient (positive or negative) shows the direction of the effect. In multiple regression models the coefficient shows how much the dependent variable is expected to increase when that independent variable increases by one, holding all the other independent variables constant.

4. The t statistic: is the coefficient divided by its standard error.

5. P-value (F statistic of the model): if this is 0.05 or less, the null hypothesis is rejected.

3.3.4 EU country data (focus energy efficiency)

Finally DEA was used to assess energy efficiency across selected EU member states. In this DEA application the following variables are used: final energy consumption, GDP, labour, capital, population density, SOx emissions (from energy), NOx emissions (from energy) and GHG emissions (from energy) with data obtained from Eurostat. In total 28 EU Member States are studied for the years 2008, 2010, 2012, 2014 and 2016. The parameters are counted in the following units for this analysis:

- Final energy consumption: million tonnes equivalent

- GDP: current prices (million Euro)
- Labor: number of people (thousand people)
- Capital: gross fixed capital formation - current prices, million Euro
- Population density: person per km^2
- SOx emissions: tonnes (from energy production and distribution)
- NOx emissions: tonnes (from energy production and distribution)
- GHG emissions: thousand tonnes of CO_2 equivalent (from energy production and distribution)

Table 15 presents the descriptive statistics of the inputs and outputs used in the different DEA model formulations and for all the years and for all the examined countries.

Table 15: Descriptive statistics for all DEA models

	Final energy consumption (million tonnes equivalent)	GDP (million €)	Labor (thousand persons)	Capital (million €))	Population Density (persons per km²)	SOx emissions (tonnes)	NOx emissions (tonnes)	GHG emissions from energy (thousand tonees of CO_2 equivalent)
2008								
Mean	42.1	1,781,373.4	7,986.4	104,801.4	169.6	130,041.6	74,443.1	142,163.4
St. dev	56.0	5,096,821.3	10,180.0	148,216.2	243.2	176,282.2	100,320.9	197,222.1
Min	0.5	6,128.7	158.6	1,203.1	17.5	12.0	783.0	2,833.4
Max	217.6	27,193,630.0	38,541.5	520,809.0	1,295.5	628,644.0	382,978.0	820,242.4
2010								
Mean	41.5	1,787,110.4	7,774.2	91,911.8	171.4	96,084.9	66,404.0	135,553.4
St. dev	55.5	5,103,808.5	10,076.9	136,804.0	246.3	132,887.3	94,477.9	189,697.4
Min	0.5	6,599.5	162.6	1,411.6	17.6	11.0	863.0	2,598.1
Max	219.7	27,224,599.0	38,737.8	501,449.0	1,311.7	545,404.0	334,748.0	802,121.3
2012								
Mean	39.6	1,878,639.0	7,548.8	94,847.8	172.7	84,384.5	65,251.6	128,695.0
St. dev	53.3	5,394,392.0	9,951.5	145,091.9	249.9	119,172.7	97,298.8	183,709.8
Min	0.5	7,168.4	170.7	1,299.8	17.8	10.0	779.0	2,818.9
Max	212.1	28,781,064.0	38,320.6	554,746.0	1,329.2	485,523.0	366,449.0	785,284.2
2014								
Mean	38.0	2,058,682.8	7,622.2	97,341.0	175.1	62,735.0	55,019.0	119,113.9
St. dev	51.3	6,103,555.2	10,096.1	150,749.6	258.2	94,256.0	85,032.2	173,002.8
Min	0.5	8,505.4	186.8	1,465.4	18.0	15.0	728.0	2,470.1

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Max	208.9	32,583,424.0	38,907.7	587,549.0	1,375.2	425,649.0	300,824.0	762,351.1
2016								
Mean	39.6	2,235,599.6	7,819.9	106,622.6	178.8	43,531.1	46,821.9	119,581.1
St. dev	53.1	6,647,143.6	10,365.3	160,493.8	271.3	67,884.9	72,540.6	173,095.0
Min	0.6	10,343.0	204.6	2,435.6	18.1	17.0	612.0	1,426.9
Max	216.4	35,474,186.0	40,165.1	634,029.0	1,450.2	296,757.0	295,747.0	771,900.6

Based on these data, Figure 43 presents the trend of energy consumption levels, GHG, NOx and SOx emissions for all examined years on an average EU basis for the 28 countries taken into account. It is noticed that all indicators have dropped since 2008 especially SOx and NOx emissions, whereas energy consumption and GHG emissions are on the rise again after 2014.

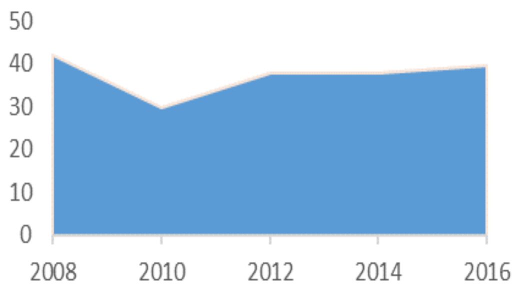


Figure 43a: Final energy consumption (million tonnes)

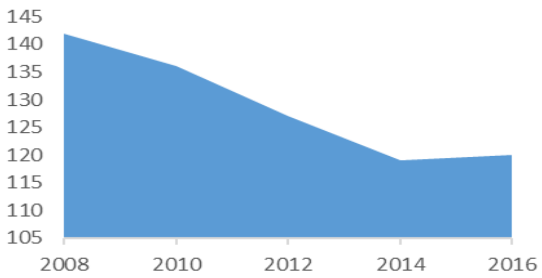


Figure 43b: GHG emissions (million tonnes)

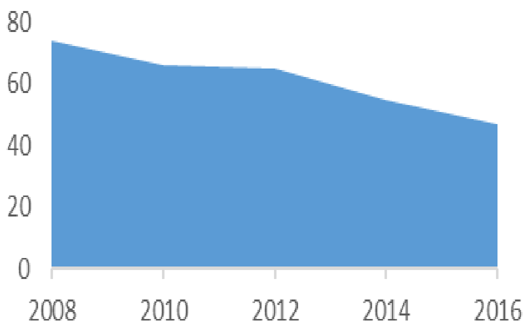


Figure 43c: NOx emissions (thousand tonnes)

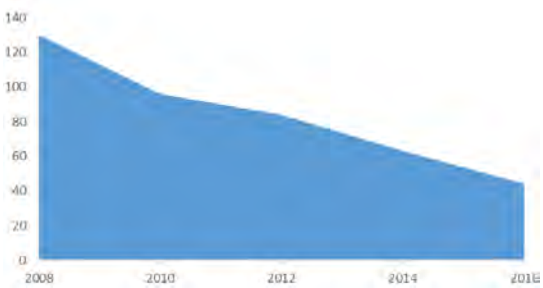


Figure 43d: SOx emissions (thousand tonnes)

Figure 43: Trend of the main components of the present analysis

3.3.5 OECD country panel data (econometric analysis)

The present research uses panel data obtained from OECD regarding 25 world counties for the years 1995-2016. These parameters are counted in the following units:

- Municipal waste/capita: Kilograms/capita
- GDP/capita: US dollars/capita
- Education level: tertiary, % of 25-64 year olds

The database used has 550 observations per variable. Looking at the raw data it can be easily noticed that MSW increases with income, having some sign of a decrease at high-income levels. In the case of missing values, adequate interpolations were applied with moving average and single and double exponential smoothing techniques employed to predict these missing values of the variables considered for the examined time period.

The determination of the appropriate method was chosen relying on the measures of accuracy like Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD) and Mean Squared Deviation (MSD). Finally Table 16 presents the descriptive statistics for the variables considered.

Table 16: Summary statistics of examined variables

Variable	**Observations**	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
MSW/capita (MSW/c)	550	482.3122	128.7479	255.6	40.59
GDP/capita (GDP/c)	550	30,034.2	14,887.16	6,302	104,702
Education Level	550	26.14075	9.66314	7.45	50.5

Following the methodology presented in this Section and the data outlined above, the following section will present the results of the current analysis in greater detail.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

4. Results

For the main part of the analysis in this Thesis, the MaxDEA for Data Envelopment Analysis programme was used (MaxDEA Basic 6.6 – 2015 edition). Section 4.1 focuses on EU regions, while Section 4.2 focuses on EU countries. Moreover Section 4.3 presents the results of the analysis on MSW and cultural dimensions, while Section 4.4 reviews the case of energy efficiency in relation to MSW. Finally Section 4.5 presents the empirical results of the panel data analysis which were conducted with econometric methods on STATA.

4.1 EU regional analysis

The present analysis builds on the work by Halkos and Papageorgiou (2014, 2015) and expands it by using more inputs and outputs and more recent EU data for EU regions. The frameworks that have been designed (Figures 44-47) are also based on their analysis with new additions in the inputs taken into account. More specifically in terms of methodology, first one of the pollutants in question, MSW generation is modelled as a regular output by applying the transformation introduced by Seiford and Zhu (2002, 2005). This is done in the first framework (M1).

Then the pollutant is treated as a regular input following studies treating pollutants as costs which the main goal is its minimisation, which is performed in M2 and M3 each time with slightly different inputs. In Framework M4 the idea of eco-efficiency is used as introduced by Kuosmanen and Kortelainen (2005) and Kortelainen (2008). For all the regions in the DEA analysis a radial model was used, which is output oriented and with variable returns to scale.

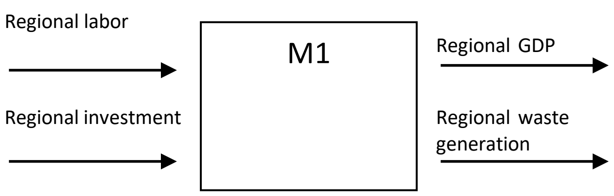


Figure 44: Description of environmental production framework (M1)

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

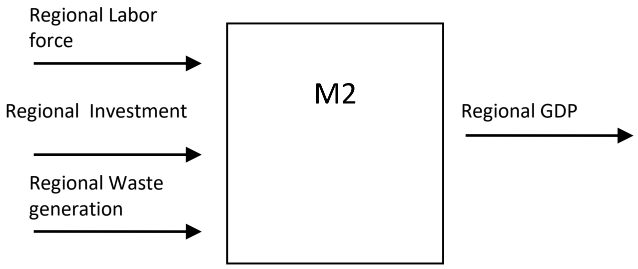


Figure 45: Description of environmental production framework (M2)

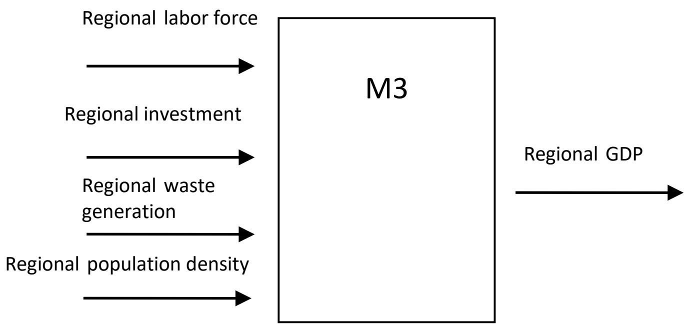


Figure 46: Description of environmental production framework (M3)

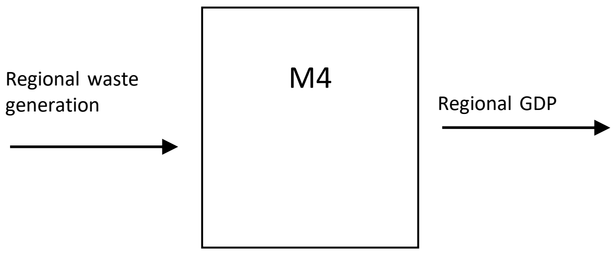


Figure 47: Description of environmental production framework (M4)

Under the M1 framework the highest performers over the years 2009-2013 are: Région de Bruxelles-Capitale (Belgium), Yuzhen tsentralen (Bulgaria), Düsseldorf (Germany), Valle d'Aosta (Italy), Liguria (Italy), Lombardia (Italy), Nord-Est (Italy), Lazio (Italy), Sicilia (Italy), Luxembourg (Luxembourg), Algarve (Portugal), Greater Manchester (UK), Surrey, East and West Sussex (UK); whereas the areas with the lowest performers are: Flevoland (Netherlands), North Eastern Scotland (UK), Severozápad (Bulgaria), Zeeland (Netherlands), Trier (Germany), Jihozápad (Czech Republic), Strední Cechy (Czech Republic), Eesti (Estonia), Highlands and Islands (UK), Moravskoslezsko (Czech Republic), Prague (Czech Republic).

When using framework M2 and by treating the bad output as input, the highest performers are: Bremen (Germany), Greater Manchester (UK), Luxembourg (Luxembourg), Région de Bruxelles-Capitale (Belgium), Düsseldorf (Germany), Valle d'Aosta (Italy), Lombardia (Italy), Nord-Est (Italy), Lazio (Italy), Surrey, East and West Sussex (UK). The lowest performers are: Yugoiztochen (Bulgaria), Strední Cechy (Czech Republic), Severozápad (Czech Republic), Highlands and Islands (UK), Dél-Dunántúl (Hungary), Zeeland (Netherlands), North Eastern Scotland (UK), Észak-Alföld (Hungary), Yugozapadna i yuzhna tsentralna (Bulgaria) and Flevoland (Netherlands).

Framework M3 is similar to M2 but with the addition of an extra input, population density. In this one the highest performers are: Region de Bruxelles-Capitale (Belgium), Severozapaden (Bulgaria), Düsseldorf (Germany), Valle d'Aosta/Vallée d'Aoste (Italy), Lombardia (Italy), Nord-Est (Italy), Emilia-Romagna (Italy), Toscana (Italy), Lazio (Italy), Luxembourg (Luxembourg), Zuid-Nederland (Nerherlands), Região Autónoma dos Açores (Portugal), Surrey, East and West Sussex and Highlands and Islands (both UK). Under this framework the worse performers are: Flevoland (Netherlands), Severozápad (Czech Republic), Strední Cechy (Czech Republic), Zeeland (Netherlands), Moravskoslezsko (Czech Republic), Yugoiztochen (Bulgaria), Dél-Dunántúl (Hungary), Észak-Alföld (Hungary), Podkarpackie (Poland), Nyugat-Dunántúl (Hungary) and Praha (Czech Republic).

From framework M4, the highest performers are: Lombardia (Italy), Valle d'Aosta (Italy), Nord-Est (Italy), whereas the lowest ones are: Severozapaden (Bulgaria), Severen tsentralen (Bulgaria), Severoiztochen (Bulgaria), Yugoiztochen (Bulgaria), Yuzhen tsentralen (Bulgaria), Dél-Dunántúl (Hungary), Malta (Malta), Észak-Magyarország (Hungary), Algarve (Portugal), Opolskie (Poland).

As it is evident from this analysis, different frameworks return different results, namely the results from M1 are much different to M2, M3 and M4 which show a kind of similar picture overall. This difference can be explained by the fact that in M1 the bad output (waste generation) is actually considered as output, whereas in the other three frameworks it is considered as a normal input. Table

1.1. (Appendix 1) below presents in detail the efficiency scores of M1, M2, M3 and M4 framework for all regions for years 2009, 2011 and 2013. Moreover Table 1.2 (Appendix 1) shows the average scores of each region for all the years per framework option.

The results of each framework cannot be compared to each other though as different assumptions are taken into account under each modelling framework. According to EEA (European Environment Agency, 2015b) and other researchers, there are fluctuations in waste generation not only among the countries but also among regions within a country, which is due to the fact that there are separate waste management strategies among the regions themselves as well. This study's results are in agreement with this idea, as it was shown that certain regions from one country can be at the top environmental performers whereas other regions from the same one can be among the lowest ones.

Furthermore Table 1.3 (Appendix 1) presents the descriptive statistics per country of the different environmental frameworks over the examined period. The results show that on average terms the environmental efficiency scores regarding waste arising on a regional level are higher in framework M1 compared to the environmental efficiency scores from M2, M3 and M4. Overall the results obtained (on average terms) from M1 suggest that Belgium has higher environmental efficient regions followed by the regions in Italy, Portugal and the UK.

4.2 EU Country level analysis

For all 28 EU countries in this DEA analysis a radial model was used, which is output oriented. A main gap identified in the literature studied was that previous studies have not focused enough on counties' environmental efficiency in terms of MSW generation and treatment especially under the concept of the circular economy.

In terms of methodology and the frameworks designed, first one of the bad outputs (pollutant) in question, MSW generation, is modelled as a regular bad output by applying the transformation introduced by Seiford and Zhu (2002, 2005). This is done in the first two frameworks (M1 and M2), in which different inputs are taken into account and MSW (bad output) and GDP (good output) form the two outputs examined. Then in model M3 labor, capital, population density and also waste are considered as inputs, whereas GDP and the gas emissions from the waste sector (NOx, SOx

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

and GHGs) are being treated as good and bad outputs respectively. In this framework waste (which is generally a bad output) is being treated as a regular input.

Many researchers have pointed that a DDF approach (suggested by Fare and Grosskopf, 2004) is the best solution as it allows for simultaneous increase in desirable outputs and reduction of undesirable outputs (Mohd et al., 2015). This also helps avoid making a random choice between input and output technical efficiency measures. Such an approach includes two sets of linear programmes, namely one of profit maximising and a second one in which technical efficiency is measured as a simultaneous reduction in the input vector and expansion of the output vector (Coelli et al., 2005). Additional advantages of this model include monotonicity, units' invariance and output translation invariance (Lin and Chen, 2017).

Several studies propose that MSW is affected by population's income as economic activities are very much related to waste generation and there is no strong evidence of decoupling MSW generation from GDP and subsequently consumption (Mazzanti 2008; Mazzanti and Zoboli 2005b, 2008). Moreover the works of Sjöström and Östblom (2010) and Halkos and Papageorgiou (2015) focus also on waste generation and its economic impacts. Based on these studies among a few relevant ones, the variables used in our proposed model formulations are justified (MSW generation, GDP, labour force, capital investment, population density and aerial gases in the form of NOx, SOx, GHGs emissions).

All the above described frameworks of inputs/outputs are presented in Figures 48-50.

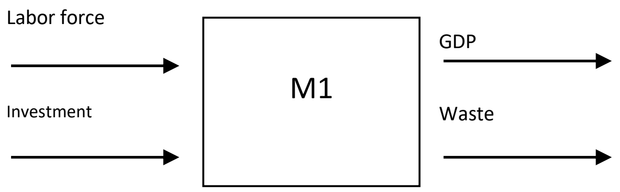


Figure 48: Description of environmental production framework (M1)

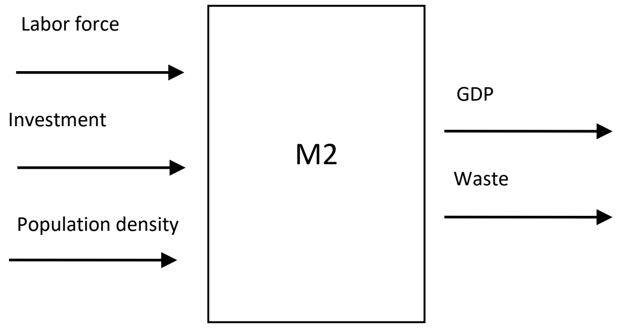


Figure 49: Description of environmental production framework (M2)

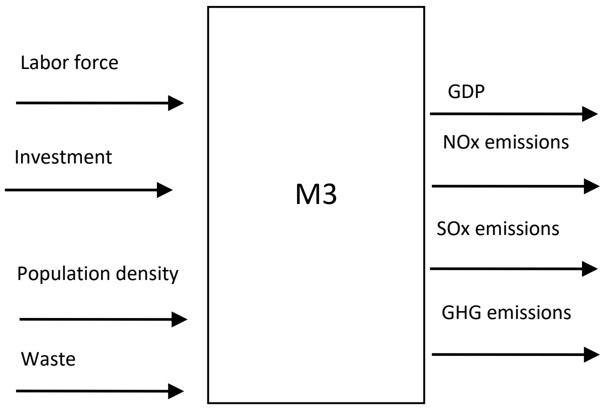


Figure 50: Description of environmental production framework (M3)

For frameworks M1 and M2, CRS was used, whereas the analysis was performed with VRS for framework M3 and all done according to the model by Simar and Wilson (1998), as shown in Table 17.

Table 17: Stata results on testing CRS vs VRS in this study's three models for all examined years

Frameworks	**2008**	**2010**	**2012**	**2014**
M1	0.8589	0.9740	0.9850	0.7007
M2	0.9590	0.9900	0.9960	0.7307
M3	0.0000	0.0000	0.0000	0.0000

The CRS model overestimates the true technical inefficiency by projecting to a technically infeasible point if the relevant technically efficient benchmark is characterised by either increasing or decreasing returns to scale (Ruggiero, 2011). Due to imperfect market information, government regulations and constraints on finance the use of VRS seems appropriate in most cases.

Under the M1 framework the highest performers are: Finland, Ireland, Luxembourg, Norway and the UK, whereas the least performing countries are: Bulgaria, Estonia, Latvia and Romania. For framework M2 the highest performing countries are: Finland, Ireland Luxembourg, Norway and Sweden. The lowest performers are: Bulgaria, Czech Republic, Latvia, Romania, and Slovakia. Finally under framework M3 the most efficient countries are: Cyprus, Estonia, Greece, Finland, Latvia, Luxembourg, Malta and Norway, whereas the least efficient are: Bulgaria, Czech Republic, Romania and Slovakia.

Table 1.4 (Appendix 1) presents the efficiency scores over the years for the three different frameworks. Also Table 1.5 (Appendix 1) presents the average scores (year-wise) per country per modelling framework.

However, the results obtained are biased and therefore following the bootstrap technique presented in Section 3.1.3, the biased corrected results need to be adopted in our analysis. Table 1.6 (Appendix 1) presents the efficiency scores of the 28 countries, the biased corrected efficiency scores, the standard deviation -std and the 95-percent confidence intervals: lower and upper bound obtained by B=999 bootstrap replications using the algorithm described in Section 3.1.3.

According to the biased corrected efficiency measures the countries with the higher environmental efficiency scores (i.e. > 0.70) over the years are reported to be:

- Framework M1: Finland, Germany, Ireland, Norway and the UK.
- Framework M2: Austria, Belgium, France, Germany, Ireland, Netherlands, Sweden and the UK.
- Framework M3: Austria, Belgium, Denmark, France, Ireland, Italy, Lithuania, Netherlands, Portugal, Slovenia, Spain, Sweden and the UK.

As it is evident these different frameworks extract different results. This difference can be explained by the fact that in M1 and M2 the bad output (MSW generation) is considered as output, whereas in framework M3 it is considered as a regular input

Different modelling techniques are not comparable among them since they take into account diverse assumptions. It can be clearly observed that the lack of a uniform environmental policy among the European countries is reflected upon their environmental efficiency levels regarding MSW generation and treatment.

Regarding changes over the years in all models, there is not much difference showing that probably not many alterations have been implemented in these countries and possibly also a lack of coherent EU environmental policy in place. What is also strangely noticed is that the environmental efficiency scores in all models tend to be lower in 2014 under all modelling frameworks and again this shows the lack of policies' implementation in the EU member states examined and seems to be highly related to the worsening of the financial crisis that has hit Europe severely especially in the last 7 years.

4.3 Cultural dimensions and 'waste culture' (EU countries)

For this part of the analysis, it is identified that the Charnes et al. model is more appropriate which allows constant returns to scale as the results obtained are higher than 0.05 thus accepting the null hypothesis (B = 999). In more detail in this application two models were used as shown in Table 18.

Table 18: Stata results on testing CRS vs VRS in this study's two models for all examined years

Frameworks	**2005**	**2010**	**2015**
M1	0.2442	0.1051	0.4124
M2	0.7157	0.4164	0.8418

In terms of methodology, the bad output (pollutant) in question, MSW generation, is modelled as a regular bad output by applying the transformation introduced by Seiford and Zhu (2002, 2005). In the two proposed models, different inputs are taken into account and MSW (bad output) and GDP (good output) form the two outputs examined.

For all 22 countries in the DEA analysis a radial model was used, which is output oriented and under CRS as mentioned above. The above described frameworks of inputs/outputs are presented in Figures 51 and 52.

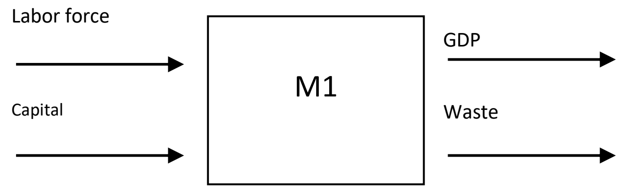


Figure 51: Description of environmental production framework (M1)

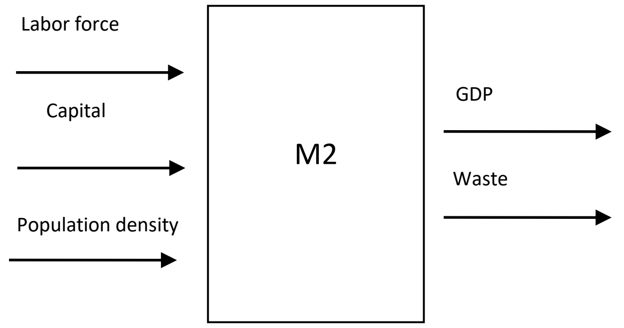


Figure 52: Description of environmental production framework (M2)

According to the bias corrected efficiency measures the countries with the higher environmental efficiency scores (i.e. > 0.80) over the years are reported to be:

- Framework M1: Denmark, Greece, Italy, Netherlands and Poland.
- Framework M2: Denmark, Finland, Greece, Italy, Netherlands, Poland and Sweden.

Tables 1.7 and 1.8 (Appendix 1) present the efficiency scores of the 22 countries, the bias corrected efficiency scores and the 95-percent confidence intervals: lower and upper bound obtained by B=999 bootstrap replications using the algorithm described in Section 3.1.

Additionally multiple regression analysis was used to test if the bias corrected efficiency scores can significantly be predicted by Hofstede's and Schwartz's cultural dimensions for both frameworks and for all the years examined. The regression results are presented and explained in Table 19 for Hofstede's cultural dimensions and Table 20 for Schwartz's ones.

Table 19: Multiple regression analysis results for Hofstede's cultural dimensions

Results per year/ modelling framework	**M1**	**M2**
2005	• R^2=0.3551 – Low predictability indicating only 35.51% of variation in efficiency scores is explained • p-value of F stat = 0.2862 indicating no significant overall statistical relationship between the variables	• R^2=0.2930 – Low predictability indicating only 29.3% of variation in efficiency scores is explained • p-value of F stat = 0.4406 indicating no significant overall statistical relationship between the variables
2010	• R^2=0.7426 – High predictability indicating that 74.26% of variation in efficiency scores is explained model • p-value of F stat = 0.0006 statistically significant suggesting that changes in predictors affect the response variable	• R^2=0.7845 - High predictability indicating that 78.45% of variation in efficiency scores is explained model • p-value of F stat = 0.0003 statistically significant suggesting that changes in predictors affect the response variable

2015	• R^2=0.5828 – Moderate predictability indicating that 58.28% of variation in efficiency scores is explained • p-value of F stat = 0.023 < 0.05 statistically significant suggesting that changes in predictors affect the response variable	• R^2=0.5086 - Moderate predictability indicating that 50.86% of variation in efficiency scores is explained model • p-value of F stat = 0.00633 statistically significant suggesting changes in predictors affect the response variable

Table 20: Multiple regression analysis results for Schwartz's cultural dimensions

Results per year/ modelling framework	**M1**	**M2**
2005	• R^2=0.1472 - Low predictability indicating that only 14.72% of variation in efficiency scores is explained • p-value of F stat = 0.9191, indicating no significant overall statistical relationship between the variables	• R^2=0.1363 - Low predictability indicating only that only 13.63% of variation in efficiency scores is explained • p-value of F stat = 0.9347 indicating no significant overall statistical relationship between the variables
2010	• R^2=0.5463 - Moderate predictability indicating 54.63% of variation in efficiency scores is explained	• R^2=0.5624 - Moderate predictability indicating 56.24% of variation in efficiency scores can be explained

	• p-value of F stat = 0.0766 <0,10 significant at 0,10 significance level suggesting changes in predictors affect the response variable	• p-value of F stat = 0.0629 <0,10 significant at 0,10 significance level suggesting changes in predictors affect the response variable
2015	• R^2=0.7160 - High predictability indicating that 71.6% of variation in efficiency scores is explained • p-value of F stat = 0.0050 showing an overall statistically significant relationship between the variables	• R^2=0.5764 - High predictability indicating that 57.6% of variation in efficiency scores is explained • p-value of F stat = 0.00526 showing an overall statistically significant relationship between the variables

Results show that for the year 2005 no significant relationship is noticed between the efficiency scores and the cultural dimensions' data from both models, whereas for years 2010 and 2015 there appears to be a significant connection with changes in the predictors also affecting the response variable. Moreover for years 2010 and 2015, the R^2 provides support for the assumed relationship between culture and environmental efficiency in the examined EU member states.

4.4 Energy efficiency and MSW (EU countries)

This analysis of the Thesis deals with energy efficiency and it identifies that for the problem in hand CRS is more appropriate following the Charnes et al. (1978) model as the results obtained are higher than 0.05 thus accepting the null hypothesis (B = 999). The specific results are shown in Table 21.

Table 21: Stata results on testing CRS vs VRS in this study's two models for all examined years

Frameworks	2008	2010	2012	2014	2016
M1	0.6507	0.8809	0.2252	0.5075	0.4795
M2	0.6016	0.8138	0.3393	0.5736	0.5816

Following studies such as Wang et al. (2013) and Chien and Hu (2007) where capital, labor and energy consumption are used as inputs and GDP (desirable output), carbon dioxide and sulphur dioxide (undesirable outputs), this analysis produces two production frameworks as presented in Figures 53 and 54. In both frameworks a radial model is used, which is output oriented.

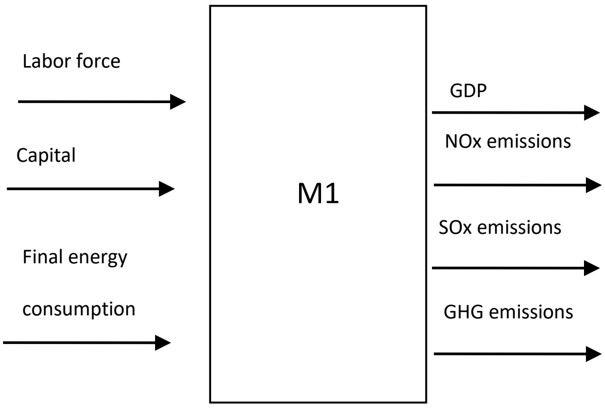


Figure 53: Description of environmental production framework (M1)

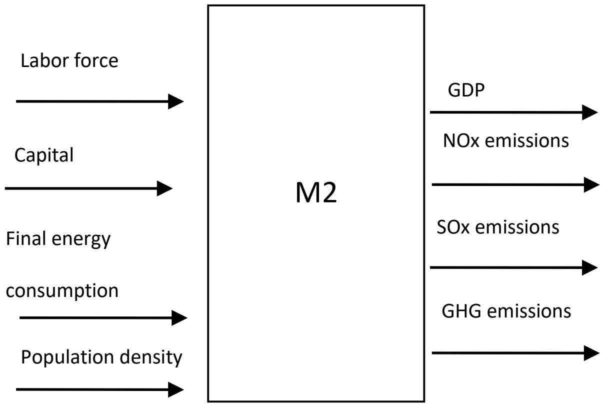


Figure 54: Description of environmental production framework (M2)

Under the M1 framework the highest performers are: Hungary, Luxembourg, Sweden; whereas the lowest performers are: Estonia, Bulgaria, Greece and Slovenia. For framework M2 the picture is quite similar.

Table 1.9 (Appendix 1) presents the efficiency scores over the years for the two frameworks. Also Table 1.10 (Appendix 1) presents the average scores (year-wise) per country per modelling framework.

However, the results obtained are biased and therefore following the bootstrap technique presented in Section 3, the bias corrected results need to be adopted in our analysis. Table 1.11 (Appendix 1) presents the efficiency scores of the 28 countries, the bias corrected efficiency scores and the 95-percent confidence intervals: lower and upper bound obtained by B=999 bootstrap replications using the algorithm described in Section 3.

According to the bias corrected efficiency measures the countries with the higher environmental efficiency scores (i.e. > 0.497) over the years are reported to be:

- Framework M1: Bulgaria, Cyprus, Estonia, Greece, Lithuania, Malta and Slovenia.
- Framework M2: Bulgaria, Cyprus, Estonia, Greece, Lithuania and Slovenia.

Different modelling techniques are not comparable among them since they take into account diverse assumptions and inputs/outputs. It can be clearly observed that the lack of a common environmental policy among European countries is reflected upon their environmental efficiency levels regarding energy consumption and the relevant emissions.

Regarding changes over the years and as can be seen in Figure 55, most countries seem to maintain their efficiency scores with only Czech Republic, Finland, Ireland, Malta, Romania and Slovenia marginally improving theirs. At the same time, it can be noticed that most countries have higher environmental efficiency scores over 2010 and 2012 with a decrease after that.

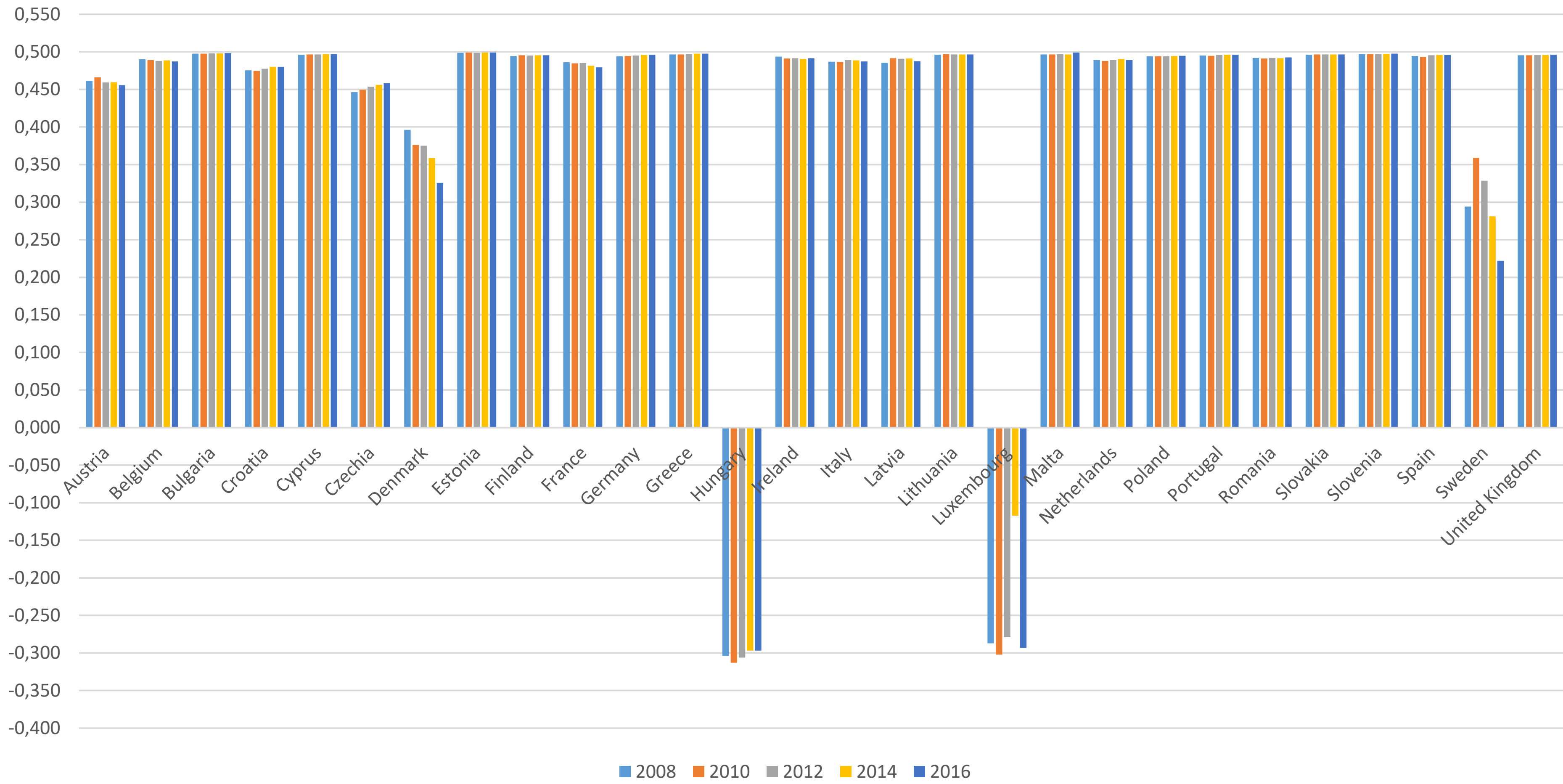


Figure 55: Bias corrected efficiency scores for all countries for all examined years

4.5 Empirical results from panel data analysis (OECD countries)

Relying on the above described methodology, the current empirical analysis tests the existence of cross section dependence (CD). Test results strongly reject the null hypothesis of cross-section independence (P-value = 0.000) in all cases, providing evidence of cross-section dependence in the data given the statistical significance of the CD statistics (Table 22).

Such a dependence may be occurring due to a number of reasons: i.e. selecting individuals non-randomly, unobserved common shocks, due to a single currency and common policies (Basak and Das, 2018) or even due to spatial and spillover effects or unobserved common factors (Baltagi and Pesaran, 2007). Moreover in the case of social data it is expected that groups and their characteristics are interrelated and not independent (Stephan, 1934).

Table 22: Cross-section dependence (Pesaran CD test)

Variable	CD test	P-value	Correlation	Correlation (absolute)
MSW/c	5.60^{***}	0.000	0.069	0.412
GDP/c	78.15^{***}	0.000	0.962	0.962
$(GDP/c)^2$	76.55^{***}	0.000	0.942	0.942
$(GDP/c)^3$	74.96^{***}	0.000	0.923	0.923
Education Level	74.52^{***}	0.000	0.917	0.917

Note: Under the null hypothesis of CD [CD~N(0,1)].

Correlation and Absolute (correlation) are the average (absolute) value of the off-diagonal elements of the cross-sectional correlation matrix of residuals obtained. Significance at ***1%.

Starting with the panel unit root tests a graphical examination showed the inclusion of a trend and a constant term existed in the model formulation with the lags determined by the use of Akaike (1974) and Schwarz (1978) information criteria. Table 23 presents the tests applied to the variables considered. It can be seen that there is evidence against non-stationarity in levels as in all cases the examined variables are I(1).

Table 23: ADF Fisher panel unit root tests

Variables	ADF Fisher				PP - Fisher
	inverse χ^2 statistic	inverse normal statistic	inverse logit statistic	modified inversed χ^2 statistic	χ^2 statistic
Levels					
MSW/c	37.0234 (0.9135)	1.2913 (0.9017)	1.2974 (0.9016)	-1.2977 (0.9028)	54.5756 [0.3048]
GDP/c	69.2476** (0.0370)	-0.6319 (0.2637)	-1.0323 (0.1519)	1.9248** (0.0271)	50.208 [0.4651]
$(GDP/c)^2$	32.5562 (0.9734)	1.7938 (0.9636)	1.7414 (0.9579)	-1.7444 (0.9595)	63.8222 [0.9505]
$(GDP/c)^3$	24.2221 (0.9992)	5.9824 (1.0000)	6.5488 (1.0000)	-2.5778 (0.9950)	71.7032 [0.9334]
Education Level	36.8732 (0.9163)	1.2376 (0.8921)	1.3660 (0.9128)	-1.3127 (0.9054)	78.2909 [0.0052]
First Differences					
Δ(MSW/c)	123.7869*** (0.0000)	-3.2775*** (0.0005)	-4.7087*** (0.0000)	7.3787*** (0.0000)	257.084*** [0.0000]
Δ(GDP/c)	123.4616*** (0.0000)	-5.0654*** (0.0000)	-5.5120*** (0.0000)	7.3462*** (0.0000)	244.967*** [0.0000]
$\Delta(GDP/c)^2$	128.4535*** (0.0000)	-5.0596*** (0.0000)	-5.6494*** (0.0000)	7.8454*** (0.0000)	418.576*** [0.0000]
$\Delta(GDP/c)^3$	132.4456*** (0.0000)	-4.7306*** (0.0000)	-5.4094*** (0.0000)	8.2446*** (0.0000)	525.321*** [0.0000]
Δ(Education Level)	79.5404*** (0.0049)	-2.9762*** (0.0015)	-2.9353*** (0.0020)	2.9540*** (0.0016)	312.518 [0.0000]

Note: The null hypothesis assumes that the variable contains unit root. Numbers in parentheses denote P-values. Significance at ***1%, **5% and *10%.

Table 24 presents the Westerlund co-integration test values. From the G_t and G_a statistics H_0 is rejected only in the former, implying cointegration for at least one unit. From the P_t and P_a statistics, H_0 is rejected implying cointegration for the panel in total.

Table 24: Westerlund ECM panel cointegration tests

Equation	Statistic			
	G_τ	G_α	P_τ	P_α
MSW/c = f (GDP/c)	-3.411*** (0.0000)	-6.529 (0.7770)	-11.186*** (0.0040)	-3.384*** (0.0000)
MSW/c = f $(GDP/c)^2$	3.512*** (0.0000)	-8.432 (0.9950)	-12.550*** (0.0100)	-2.998*** (0.0000)
MSW/c = f $(GDP/c)^3$	3.668*** (0.0000)	-9.294 (0.975)	-13.637*** (0.0000)	-3.214*** (0.0000)
MSW/c = f (Educatiom level)	3.349*** (0.0000)	-11.647 (0.575)	-13.996*** (0.0000)	-9.679 (0.2720)

Note: *Test regression fitted on a constant and trend with one lag and lead. Kernel bandwidth was set following Demetriades and James (2011). The null hypothesis assumes that there is no co-integration. Numbers in parentheses are P-values. Significance at ***1%, **5% and *10%.*

Similarly, Table 25 presents the Pedroni Cointegration tests with eight of the eleven cases rejecting the null hypothesis of no-cointegration at the conventional statistical significance levels.

Table 25: Pedroni Residual Cointegration Test

	Statistic	Prob.	Weighted Statistics	Prob.
Panel v-Statistic	0.700791	0.0000	0.565726	0.2992
Panel rho-Statistic	-1.773241	0.0299	-1.275758	0.1042
Panel PP-Statistic	-2.144834	0.0160	-2.009076	0.0223
Panel ADF-Statistic	-1.449334	0.0029	-1.998793	0.0068

	Statistic	Prob.		
Group rho-Statistic	3.109888	0.9660		
Group PP-Statistic	-1.946870	0.0258		
Group ADF-Statistic	-2.251362	0.0122		

Table 26 presents the results of both FE and RE model specifications for the static analysis (2nd and 3rd columns) and then for the dynamic formulation (4th and 5th columns) for the best quadratic and cubic formulations respectively. The Hausman test implies the use of FE model specifications. According to the Pesaran CD test the null hypothesis that errors are independently distributed across countries is rejected and this is the justification for estimating FE with Driscoll-Kraay standard errors with the variance-covariance matrix corrected for the presence of serial and spatial correlation (Camarero et al., 2011).

Moreover, Table 26 shows various diagnostic tests with three tests for heteroskedasticity and two for specification errors. In the case of the static formulations all tests indicate no problem of heteroskedasticity and specification errors especially in the full model (column 3rd). In the case of the dynamic formulations it seems that problems of both hetroskedasticity and misspecification are noticed for 10% levels of significance in the first model (column 4th) and no problem in the second specification (column 5th). Finally, for the dynamic specifications none of the first- and second-order serial correlation tests shows verification that serially uncorrelated errors hypothesis is inappropriate.

A number of random coefficients models were also analysed with the variables in logs or levels and with quadratic and cubic GDP/c terms. In all cases both GDP/c and GDP/c squared were statistically insignificant showing vast cross-country variation in β_i's and that even if an inverted 'U' shape relationship exists its parameters are extremely heterogeneous across countries with any aggregation being useless. The magnitude of education ranges from 1.7 to 2.5 with negative effect in any instance. This negative coefficient of education coincides with the expectation of the present analysis, namely as education increases, MSW tends to decrease.

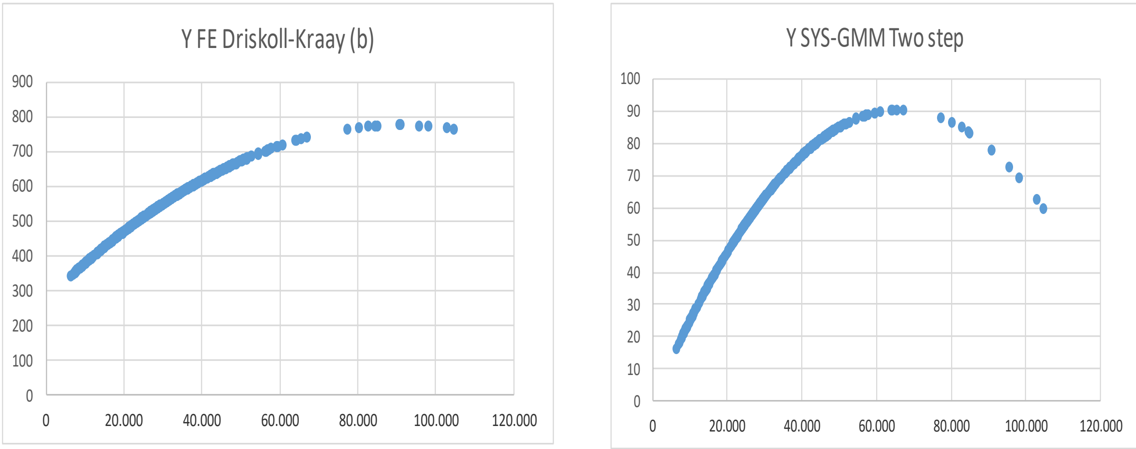
Concerning the static specifications in all cases all variables are statistically significant and properly signed in all levels of significance. The calculated turning points are quite high but within the sample. Specifically, they are high in the static specifications having values of 91,560$ in the simple model and 98,098$ in the full model. Looking at the dynamic model specifications and in the case of

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

System-GMM GDP and its powers, education and the lag of MSW are statistically significant in all significance levels with a valid inverted U-shape relationship and lower turning points compared to the static specifications within the sample ranging from 26,894$ to 64,364$.[5]

In the dynamic models much lower turning points are found equal to 64815$ and 66184$ for the one- and two step GMM system specifications respectively. Moreover in Table 26, the system GMM estimates indicate the presence of an inverted U-shape relationship between countries' MSW/c, economic growth and education with statistically significant parameter estimates. Figure 56 presents the extracted relationships for the static (a) and dynamic (b) specifications.



(a) (b)

Figure 56: Derived relationships (x axis represents GDP levels (US dollars/capita), whereas y axis represents MSW levels (kilograms/capita))

The use of the lags of the dependent variable refer to the autoregressive-distributed lag specification ending up to an AD (1,0) formulation omitting insignificant dynamics. It is assumed that variables except the lagged dependent are strictly exogenous. The adjustment coefficients are quite low for MSW equal to 0.113 and 0.142 in the cases of one and two step system GMM respectively.

[5] Regarding the theoretical underpinnings justifying the existence of an inverted U-shape and N-shape relationships see Halkos (2013b) and Halkos (2012).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Table 26: Empirical findings with different specifications

	Static		Dynamic	
Model	**FE Driskoll-Kraay s.e. (a)**	**FE Driskoll-Kraay s.e. (b)**	**SYS-GMM One-step**	**SYS-GMM Two-step**
Constant	266.2972*** [0.0000]	274.2088***[0.0000]	62.588	
GDP/c	0.0088877*** [0.0000]	0.010914***[0.0000]	0.00175	0.00274
$(GDP/c)^2$	-4.53e-08*** [0.002413]	-5.96E-08*** [0.002413]	-1.35e-08	-2.07e-08
Education		-2.0175 [0.0000]	-1.6587*** [0.0807]	-2.4994*** [0.0807]
$(MSW/c)_{t-1}$			0.8867*** [0.0000]	0.8577*** [0.0000]
Hausman Test		10.75 [0.0010]	0.55 [0.4603]	0.55 [0.4603]
Pesaran's cross-sectional dependence	48.549 [0.0000]	27.483 [0.0000]	1.959 [0.0501]	0.761 [0.4469]
Wald test			1929.29*** [0.0000]	1872.55*** [0.0000]
AR(1)			-3.78*** [0.0000]	-3.54 [0.0010]
AR(2)			0.77 [0.4436]	0.79 [0.4971]
Hansen test			31.11 [1.0000]	31.72 [1.0000]
Test 1 (heteroskedasticity)	1.14 [0.3308]	1.08 [0.3411]	1.06 [0.289]	0.31 [0.753]

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Test 2 (heteroskedasticity)	2.90 [0.0338]	0.82 [0.4423]	0.29 [0.775]	1.41 [0.159]
Test 3 (heteroskedasticity)	2.77 [0.0962]	2.01 [0.1561]	0.86 [0.391]	1.46 [0.144]
Test 4 (RESET 1)	3.12 [0.078]	1.30 [0.2730]	2.97 [0.0516]	0.43 [0.67]
Test 5 (RESET 2)	2.40 [0.0962]	1.42 [0.2411]	5.66 [0.0000]	0.11 [0.912]
Shape of curve	Inverted U-shape	Inverted U-shape	Inverted U-shape	Inverted U-shape
Turning Points	91560	98098	64815	66184
Observations	550	550	519	519

Test 1: Regression of the squared residuals on X. That is, $u_t^2 = x_t'\gamma_1 + v_{t,1}$

Test 2: Regression of absolute residuals on X. That is, $|u_t| = x_t'\gamma_2 + v_{t,2}$ *(a Glejser test)*

Test 3: Regression of the squared residuals on $\hat{Y}$

Test 4: Regression of residuals on $\hat{Y}^2$

Test 5: Regression of residuals on $\hat{Y}^3$

P-values in brackets. SYS-GMM is the system GMM estimator.

The numbers in square brackets denote P-values.

AR(1) and AR(2) are tests for first and second order serial autocorrelation.

The Likelihood Ratio (LR) test denotes joint significance of all the covariates.

Hansen denotes the test of over identifying restrictions of the instruments.

*Significance at ***1%, **5% and *10%.*

Apart from the main results, it is worth mentioning that the rate of adjustment with which efficiencies adjust to their equilibrium values is slow. The lag coefficient in the estimated equation shows that the adjustment of economic efficiency proceeds at a rate of around 33% per annum. This implies that 14% of the discrepancy between the desired and the actual levels of economic efficiencies are adjusted in a year.

It can also be inferred that the adjustment of economic efficiency is effected within almost seven periods. The causes of this very slow adjustment of economic efficiency should be sought mainly in countries' MSW management policies, education level and in their differences on their growth processes overall.

Following the results' analysis of all parts of this Thesis in this Section, the following section (Section 5) will discuss these in relation to the EU's and worldwide current trends in order to understand what these mean and their potential implications.

5. Discussion

The present section considers the main findings of the analysis and firstly discusses the main findings of the DEA analysis both on a regional (Section 5.1) and country level (Section 5.2). Then the findings of the cultural dimensions and MSW management are discussed in Section 5.3, while Section 5.4 reviews the implications of the energy efficiency research in relation to MSW. Finally Section 5.5 evaluates the econometric results from the panel data OECD country analysis.

5.1 DEA EU regional level analysis

The efficiency scores obtained through DEA from the EU regional level analysis, have been reviewed against the treatment options that have been employed in each region and which for this analysis include landfill, incineration, material recycling and composting. Data for the treatment options have been obtained from Eurostat as well. First of all it is worth mentioning that overall in the EU a decrease in the use of landfill and an increase in the use of more sustainable treatment options has been noticed over the period 1995-2015 (Figure 57).

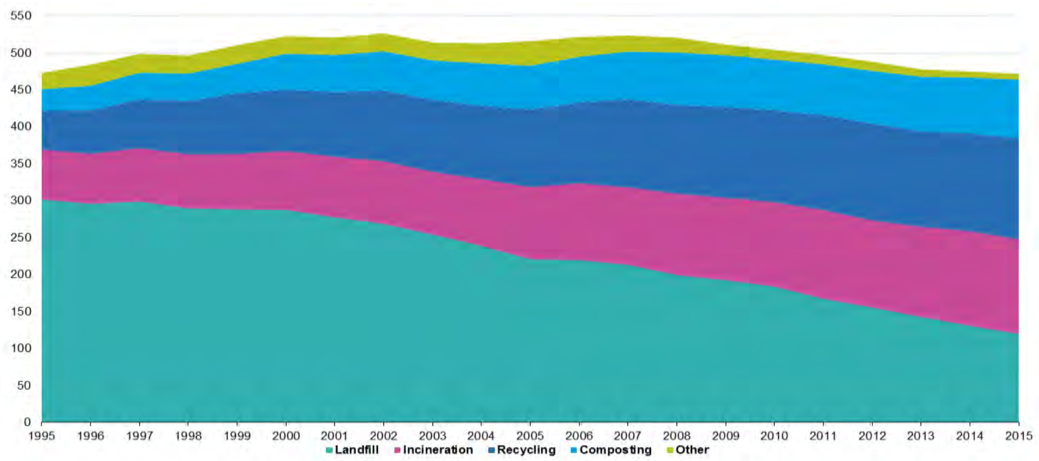


Figure 57: Municipal waste treatment per treatment option (1995-2015) (Eurostat, 2017)

The aim of the comparison in this analysis was to investigate whether regions with the use of more sustainable treatment options are the ones that are the highest performers regarding efficiency based on the DEA analysis. Table 27 presents the treatment options that have been used for the highest performing regions, whereas Table 28 presents those options for the lowest performers.

Table 27: Treatment options for highest performers overall (Y – yes, N – no)

Most frameworks – high performers	Landfill	Incineration	Material Recycling	Composting
Brussels	N	Y – most treated	Y	Y
Yuzhen tsentralen	Y	No data	No data	No data
Düsseldorf	No data	Y –most treated	Y	Y
Valle d'Aosta	Y – most treated	N	No data	Y
Liguria	Y	N	No data	Y
Lombardia	Y	Y	No data	Y
Lazio	Y	Y	No data	Y
Sicilia	Y	N	No data	Yes
Luxembourg	Y	Y –most treated	Y	Y
Algarve	Y	N	Y	Y
Manchester	Y	Y	Y	Y
Surrey etc.	Y	Y	Y	Y

Table 28: Treatment options for lowest performers overall (Y – yes, N – no)

Most frameworks – lowest performers	Landfill	Incineration	Material Recycling	Composting
Severozápaden	Y	No data	No data	No data
Zeeland	Y	Y – most treated	Y	Y
Flevoland	Y	Y – most treated	Y	y
Strední Cechy	No data	No data	No data	No data
Dél-Dunántúl	Y – most treated	N	Y	Y
North Eastern Scotland	Y – most treated	N	Y	Y
Észak-Alföld	Y – most treated	N	Y	Y

It was noticed that higher performing regions generally employ all four treatment options and for some landfill is still in extensive use for the majority of the waste treated. In Brussels and Luxembourg metropolitan regions incineration is mostly used instead.

On the other hand for the lowest performing regions generally landfill is used mostly in those ones with a small mix of other more sustainable options and with the exceptions of Flevoland and Zeeland, both regions of the Netherlands, which use mostly incineration.

These results are not unexpected because we need to account for the transport of waste between regions within a country and also the general trade of waste between countries. Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste aims at managing all the procedures around controlling waste shipments and to improve environmental protection in whole (Municipal Waste Europe, 2017).

In those regards the principles of self-sufficiency, proximity of waste for disposal and prior informed consent need to be considered (Municipal Waste Europe, 2017). The growth in exports of waste in the EU can be attributed to a number of factors, mainly the recycling targets set in the waste directives, disparities in recycling infrastructure between EU Member States, increasing prices for secondary materials and increasing demand for materials, especially in Asian countries (European Environment Agency, 2012). For instance Table 29 presents the main export and import countries for the top 10 non-hazardous wastes for 2013.

Table 29: Imports and exports of non-hazardous waste in the EU (Eurostat, 2016)

LoW description	LoW code	Recovery of disposal code[6]	Quantity in tonnes	Exporting country	Quantity in tonnes	Importing country	Quantity in tonnes
Combustible waste (refuse derived fuel)	191210	R1	2,383,688	United Kingdom	1,697,597	Netherlands	1,080,122
		Mix	79,838	Netherlands	220,628	Germany	508,908
		R13	5,490	Belgium	146,565	Sweden	264,772

[6] The recovery and disposal codes could refer to the operations included in Annex IA of the WashipR and Annexes I and II of the Waste Framework Directive.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

	Total of 191210		**2,477,061**		**2,477,061**		**2,477,061**
Other wastes (including mixtures of materials) from mechanical treatment of wastes other than those mentioned in 19 12 11	191212	R1	913,253	United Kingdom	265,580	Netherlands	467,386
		Mix	106,213	Netherlands	240,722	Germany	334,678
		D10	84,810	Austria	198,289	Slovakia	136,194
	Total of 191212		**1,243,649**		**1,243,649**		**1,243,649**
Wood other than mentioned on 19 12 06	191207	R1	871,483	United Kingdom	504,649	Germany	419,984
		R3	329,897	Netherlands	420,344	Sweden	382.731
		R12	15,912	Germany	171,643	Netherlands	155,813
	Total of 191207		**1,227,070**		**1,227,070**		**1,227,070**
Mixed municipal waste	200301	D10	424,959	Netherlands	269,891	Germany	278,264
		R1	142,949	Germany	170,590	Switzerland	157,509
		R3	13,930	Ireland	112,379	Netherlands	100,022
	Total of 200301		**583,493**		**583,493**		**583,493**
Bottom ash and slag other than those mentioned in 19 01 11	190112	R5	365,037	Germany	266,395	Netherlands	364,442
		R12	157,827	Belgium	219,702	Germany	110,821
		R4	24,780	Denmark	51,962	France	72,592
	Total of 190112		**569,322**		**569,322**		**569,322**
Sludges from treatment of	190805	D10	161,865	Netherlands	95,385	Germany	187,424
		R3	48,199	Belgium	60,140	Hungary	32,326
		R1	42,593	Slovenia	35,768	France	13,813

urban waste water	**Total of 190805**		**266,815**		**266,815**		**266,815**
Soil and stones other than those mentioned in 17 05 03	170504	R5	172,963	Luxembourg	93,263	Germany	187,342
		D1	35,408	Austria	50,392	Netherlands	35,408
		Mix	19,875	Netherlands	43,715	Spain	19,155
	Total of 170504		**245,743**		**245,743**		**245,743**
Fibre rejects, fibre-, filler and coating sludges from mechanical separation	030310	R5	97,814	Germany	81,986	Czech Republic	72,136
		R3	90,533	Austria	55,452	Belgium	53,882
		R1	17,073	Netherlands	42,183	Germany	34,469
	Total of 03010		**216,511**		**216,511**		**216,511**
Mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06	170107	R5	143,466	Germany	143,466	France	90,427
						Netherlands	53,040
	Total of 170107		**143,466**		**143,466**		**143,46**
Dredging spoil other than those mentioned in 17 05 05	17 05 06	R5	135,655	Belgium	136,300	Netherlands	136,300
		D5	645				
	Total of 170506		**136,300**		**136,300**		**136,300**

This means that despite the fact that a region uses mostly landfill for example, it can also be very efficient in DEA while taking many parameters into account (population density, GDP, labor, investment). This is due to the fact that it is possible that waste produced in that area is actually treated elsewhere. The Eurostat data for the treatment options refer only to a certain region and cannot reflect waste movement in that sense, therefore it is not possible to match this waste treated with the efficiency scores of DEA on the regional level. This would make more sense in a country level analysis.

5.2 DEA EU country level analysis

The DEA results regarding the efficiency of EU countries with the parameters taken into account were contrasted to both the recycling rate of those countries and the treatment options used overall. At the moment only around 40% of the waste produced by EU households is recycled (European Commission, 2015a). Table 30 presents the recycling rates of municipal waste (as %) for the countries of our analysis.

As can be noticed from this table, the countries that have the highest recycling rates overall are Austria, Belgium, Germany, Netherlands and Sweden. Moreover Czech Republic, Estonia, Hungary, Italy, Lithuania, Poland, Portugal and the UK show an increase in their recycling rates over the years with very big increases of this share in most of these countries. These recycling rates are in agreement with the efficiency results from the DEA analysis, namely the countries that are more efficient according to DEA generally present a higher recycling rate than those inefficient ones.

Table 30: Recycling rate of municipal waste (%) (higher performers in green color) (Eurostat data)

	2008	**2010**	**2012**	**2014**
Austria	63.2	59.4	57.7	56.3
Belgium	56.2	57.7	55.7	55.1
Bulgaria	19.4	24.5	25	23.1
Cyprus	7.3	10.7	13.6	17.7
Czech Republic	10.4	15.8	23.2	25.4
Denmark	42	42.3	41	44.3
Estonia	20.2	18.2	19.1	31.3
Finland	34.3	32.8	33.3	32.5
France	33.3	34.9	36.8	39.2
Germany	63.8	62.5	65.2	63.8

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Greece	17.7	17.1	19.3	19.3
Hungary	15.2	19.6	25.5	30.5
Ireland	33.6	35.7	36.6	36.6
Italy	23.8	31	38.4	42.5
Latvia	6.4	9.4	15.8	20.5
Lithuania	8.5	4.9	23.5	30.5
Luxembourg	46	46.5	47.4	46.6
Malta	2.9	5.2	12.1	10.9
Netherlands	48.4	49.2	49.4	50.9
Norway	43.6	42.1	39.8	42.2
Poland	10.5	21.4	19.6	32.3
Portugal	17.3	18.7	26.1	30.4
Romania	0.9	12.8	14.8	13
Slovakia	7.4	9.1	13.3	10.3
Slovenia	18.9	22.4	41.9	36
Spain	39.7	29.2	29.8	32.6
Sweden	45.8	48.1	47.2	49.9
United Kingdom	36.4	40.2	42.6	43.7

Overall to raise levels of high-quality recycling, waste collection and sorting methods need to be improved, for instance by financing extended producer responsibility schemes, where manufacturers contribute to product collection and treatment costs (European Commission, 2015a). Under a circular economy approach, recycling plays a crucial role by increasing the availability of resources for the industry, by reducing the associated environmental impact and by promoting job creation and investment in the recycling sector (Exposito and Velasco, 2018). Furthermore the DEA efficiency results were contrasted to the overall treatment options (as shown in Table 31) used in the countries into consideration.

Germany is efficient under most DEA frameworks and is actually one of the countries in EU with the most incineration, material recycling and composting of waste and treats only a small amount of waste at landfills. France, Italy, the Netherlands, Spain and Sweden generally employ all treatment options with Sweden almost without any landfill treated waste, at the same time Sweden is efficient in all DEA frameworks too. The surprising result is the UK which is efficient under all frameworks but still highly relies on landfill for the year 2008 especially, but this decreases with the passing of time.

Overall though it is noticed that countries which employ all four treatment options with a higher use of more sustainable ones and a decrease in the use of landfill are the ones that also proved to be efficient according to DEA. Therefore it is possible to infer that when a country uses sustainable treatment options, it is also efficient under DEA by means of the parameters taken into account in this analysis.

These results also need to be considered under the fact that after 2010 the financial crisis has hit Europe severely. In those regards most EU countries have explored a transition to more sustainable treatment options with a high decrease in the use of landfills. This would make more sense economically as countries would be able to get back more resources which could then be used in the production process as raw material/input again.

Waste management holds a critical role in the circular economy: it determines how the EU waste hierarchy will be enforced giving priority to prevention, preparation for reuse, recycling and energy recovery through to disposal, such as landfilling (European Commission, 2015a). In the European context, the EU 2020 strategy sets out a guidance for the sustainable use of resources, which is based on a new growth model where waste is reintroduced into the production process for the production of new products or raw materials (Exposito and Velasco, 2018).

Therefore the treatment options employed by each country are very much related to the European Commission’s Circular Economy Package, which aims to accelerate Europe's transition towards a circular economy by certain legislative proposals, along with the waste reduction targets across EU member states (European Commission, 2016a). To achieve the transition to a circular economy, the value of products, materials and resources needs to be maintained in the economy for as long as possible and the generation of waste minimised (European Commission, 2017a).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Table 31: Municipal waste by waste operations (thousand tonnes)

Landfill				
GEO/TIME	2008	2010	2012	2014
Austria	373	153	207	194
Belgium	371	84	51	46
Bulgaria	3,359	3,041	2,323	2,217
Cyprus	531	490	451	398
Czech Republic	2,057	2,162	1,828	1,827
Denmark	175	130	89	56
Estonia	333	267	129	30
Finland	1,406	1,136	901	458
France	10,995	10,745	9,120	8,467
Germany	286	206	107	682
Greece	4,181	4,903	4,507	4,470
Hungary	3,341	2,838	2,609	2,181
Ireland	1,939	1,496	1,028	537
Italy	16,069	15,015	11,720	9,332
Latvia	705	617	516	515
Lithuania	1,237	1,079	971	748
Luxembourg	60	62	61	62
Malta	266	226	203	218
Netherlands	154	145	138	128
Norway	415	137	44	60
Poland	8,716	7,428	7,158	5,437
Portugal	3,530	3,381	2,593	2,307
Romania	6,486	4,813	3,427	3,558
Slovakia	1,276	1,325	1,211	1,158
Slovenia	685	571	316	208
Spain	13,091	14,789	13,263	12,023
Sweden	140	38	27	27
United Kingdom	17,590	14,686	11,277	8,656

Incineration				
GEO/TIME	2008	2010	2012	2014
Austria	1,357	1,636	1,693	1,756
Belgium	1,956	2,028	2,108	2,090
Bulgaria	0	0	0	51
Cyprus	0	0	0	4
Czech Republic	369	497	654	604
Denmark	2,186	2,025	2,387	2,385
Estonia	1	0	47	222
Finland	478	556	925	1,316
France	12,166	11,730	12,141	12,222
Germany	17,247	18,256	17,192	16,318
Greece	0	0	0	25
Hungary	393	406	364	373
Ireland	82	109	427	893
Italy	4,372	5,440	5,529	5,868
Latvia	3	0	0	0
Lithuania	0	1	0	113
Luxembourg	124	123	121	119
Malta	0	0	1	1
Netherlands	4,936	4,675	4,515	4,238
Norway	873	1,154	1,346	1,148
Poland	40	39	51	1,560
Portugal	993	1,058	930	974
Romania	0	21	89	133
Slovakia	157	183	168	190
Slovenia	13	9	10	2
Spain	2,170	2,044	2,112	2,394
Sweden	2,272	2,099	2,233	2,102
United Kingdom	3,448	4,124	5,698	8,263

Material recycling				
GEO/TIME	2008	2010	2012	2014
Austria	1,476	1,272	1,168	1,231
Belgium	1,784	1,807	1,736	1,663
Bulgaria	871	1,003	749	677
Cyprus	42	61	70	71
Czech Republic	280	452	665	736
Denmark	1,106	857	1,081	1,153
Estonia	78	41	52	125
Finland	715	495	589	474
France	5,972	6,143	7,217	7,436
Germany	22,752	22,476	23,596	23,323
Greece	797	872	869	869
Hungary	607	641	832	923
Ireland	977	910	829	829
Italy	4,631	6,107	7,177	7,732
Latvia	43	60	84	107
Lithuania	101	43	261	268
Luxembourg	89	93	96	97
Malta	8	13	20	19
Netherlands	2,450	2,354	2,196	2,111
Norway	670	609	620	567
Poland	895	1,783	1,244	2,180
Portugal	567	619	549	765
Romania	72	162	165	253
Slovakia	60	98	140	88
Slovenia	190	203	270	259
Spain	3,898	4,175	4,277	3,138
Sweden	1,520	1,414	1,403	1,418
United Kingdom	7,775	8,069	8,173	8,503

Composting				
GEO/TIME	2008	2010	2012	2014
Austria	1,683	1,520	1,650	1,492
Belgium	1,103	1,060	1,033	1,027
Bulgaria	0	0	92	59
Cyprus	0	0	7	22
Czech Republic	50	76	85	93
Denmark	606	720	639	743
Estonia	28	33	19	22
Finland	234	332	323	382
France	5,581	5,917	5,720	5,782
Germany	8,082	8,298	8,864	8,614
Greece	100	142	209	209
Hungary	85	148	183	236
Ireland	107	107	156	156
Italy	3,106	3,943	4,339	4,865
Latvia	5	4	13	26
Lithuania	15	19	51	119
Luxembourg	68	67	68	63
Malta	0	0	10	9
Netherlands	2,330	2,310	2,353	2,411
Norway	343	358	333	351
Poland	386	790	1,128	1,154
Portugal	382	399	694	665
Romania	3	650	580	391
Slovakia	64	59	81	91
Slovenia	17	22	42	62
Spain	6,158	2,767	2,245	3,446
Sweden	522	564	621	699
United Kingdom	4,402	4,786	4,788	5,091

5.3 DEA cultural dimensions and waste culture (EU countries)

Sometimes factors may be correlated but it's not obvious to see the cause and effect relationship between them, so it's important to evaluate also what is happening in the real world (Redman, 2008). Sustainability requires substantial change in our conception of natural resources (de Kadt, 1994). The analysis results presented above show that although in 2005 the cultural characteristics do not seem to have a significant relationship with the efficiency scores of each country, in 2010 and 2015 the picture is completely different.

Thus this implies that people's attitudes towards waste management have changed based on the cultural dimensions' data provided. In more detail it is possible to evaluate which specific cultural dimensions influence people's attitudes more (p-value from regression analysis < 0.05), which can be seen in summary in Table 32 for Hofstede's dimensions and Table 33 for Schwartz's ones.

Table 32: Hofstede's cultural dimensions – p value analysis

Hofstede's cultural dimensions	M1	M2
2005	None	None
2010	• Individualism vs. Collectivism • Uncertainty avoidance index • Long term vs. short term • Indulgence vs. Restraint	• Individualism vs. Collectivism • Uncertainty avoidance index • Long term vs. short term • Indulgence vs. Restraint
2015	• Individualism vs. Collectivism • Uncertainty avoidance index • Long term vs. short term	• Individualism vs. Collectivism • Long term vs. short term

Table 33: Schwartz's cultural dimensions – p value analysis

Schwartz's cultural dimensions	**M1**	**M2**
2005	None	None
2010	None	None
2015	• Conservatism • Affective autonomy • Egalitarianism	None

Among Hofstede's dimensions, individualism, uncertainty avoidance, long term orientation and indulgence were positively associated with the efficiency scores regarding waste arisings for 2010 and 2015. The relationship between Schwartz's cultural values and the DEA efficiency scores was not found to be significant apart from conservatism, affective autonomy and egalitarianism but only for year 2015. Overall findings suggest that Hofstede's cultural dimensions would be best to be considered when developing national level strategies and campaigns to manage waste arisings.

A complete cultural change towards waste management of course won't be achieved very quickly, but behavioural change can be achieved when faced with an imminent crisis (Oosthuizen, 2018). In those regards the above mentioned findings can be associated with the financial crisis that has hit Europe after 2008 making people more skeptical on environmental issues and how waste is best to be managed that will make sense financially but also environmentally.

At the same time EU jurisdiction has laid out some important Directives in the field of waste management with regards to ways of disposal, special requirements, restrictions and potential sustainable solutions (Oosthuizen, 2018). Finally along with the factors above, EU has been faced with severe environmental challenges due to waste arisings, as well as accidents and injuries for people working in this sector. In the table below (Table 34) the most important waste incidents in Europe for years after 2000 are presented.

Table 34: Waste incidents in Europe

Incident	Description	Year	Location
Spodden Valley asbestos case	Land contamination	2004	United Kingdom
Ndrangheta's own 'waste management'	Radioactive waste dumping	2005	Italy
Naples waste management crisis	Overfilled landfills	2007	Italy
Ajka alumina plant accident	Caustic waste spill	2010	Hungary
Non-compliant landfills[7]	No compliance	Based on 2015 data	1. Bulgaria: 113 non complaint. 2. Cyprus: six landfills breaching Directive. 3. Greece: Kiato landfill operating without permit since 2002 plus 78 illegal landfills and lack of management. 4. Italy: 255 landfills (16 hazardous) remaining to be cleaned up and the Malagrotta landfill in Rome and others in the region are accepting waste that has not undergone the treatment required. 5. Slovakia: no conditioning plan for landfill in Považský Chlme. 6. Slovenia: 2 illegal landfills for hazardous waste. 7. Spain: 28 non-complaint landfills remain to be closed.

[7] Watkins (2015)

All in all, it comes forward that the current economic and environmental situation across Europe has affected culture among those member states and along with the industrial symbiosis laid out in EU legislation, have led to fostering innovation and long-term culture change.

5.4 DEA and energy efficiency (EU countries)

The efficiency scores obtained and presented in Section 4.4 show that EU wise environmental efficiency levels regarding energy consumption and emissions tend to be quite low overall. The world’s tension level of energy supply is worsened over the years and efforts are being made to replace traditional fossil fuels with more sustainable options achieving a good balance between economic development and environmental protection (Song et al., 2013). Energy from waste is the largest source of renewable energy today in the EU and is expected to hold this place until 2030, reaching a share of 60–70% (UNEP, 2015).

The ‘International Energy Efficiency Scorecard’ published in 2014 by the American Council for an Energy-Efficient Economy stresses that countries can maintain their resources, address global warming, stabilize their economies and reduce the costs of their economic outputs by using energy more efficiently (Suzuki and Nijkamp, 2016). This can be seen graphically also in Figure 43 where a decrease in emissions’ level is generally noticed. The results obtained from the current analysis are also in connection with the EU’s targets for energy and climate as presented in Figure 58.

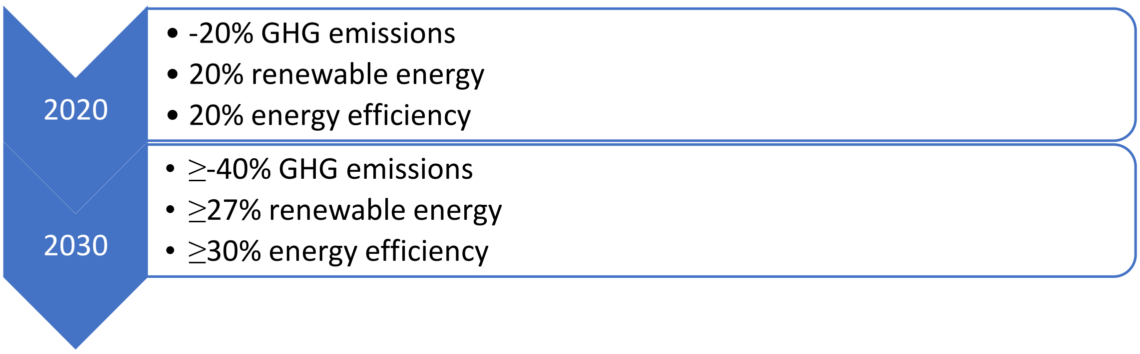


Figure 58: EU’s framework for energy and climate for 2020 and 2030 (European Commission, 2017b)

In connection to that, nations have been moving towards waste-to-energy with two main objectives, namely sufficient and sustainable energy production and effective treatment of MSW by reducing its volume by about 87% (Miranda and Hale, 1997). Both these two factors need to be taken into account when considering this option (Miranda and Hale, 2005).

A major issue to make sure this option is viable both from an economic and an environmental perspective is to take into consideration the resource characteristics, such as their location, amount and quality (Milbrandt et al., 2018). Energy efficiency should be considered to avoid unnecessary entropy production but also to make processes more cost effective and ecofriendly (Krajacic et al., 2016). The main benefits from waste-to-energy include (WWF, 2012):

- It transforms waste from a problem into a resource.
- Energy generated contributes to primary energy savings from other energy sources.
- It can reduce greenhouse-gas emissions when it replaces more carbon-intensive energy sources.
- Waste to landfill is reduced heavily.
- Waste treatment time is extremely short compared with landfills.
- It also enables treatment of hazardous waste.

At the same time, the main associated risk is that those systems become highly dependent on and justify societies' increasingly uneconomical consumption levels, while also having unintended negative effects (such as higher levels of energy and material use throughout a society, increasing upstream environmental impacts) (WWF, 2012).

Moreover it is essential to create a network of the waste by-products, electricity and heat between multiple sectors throughout the world (Geng et al., 2016). Figure 59 presents a map of waste-to-energy plants in Europe for 2017, whereas capacity is seen to be overall stable compared to 2016, with only the UK increasing its capacity.

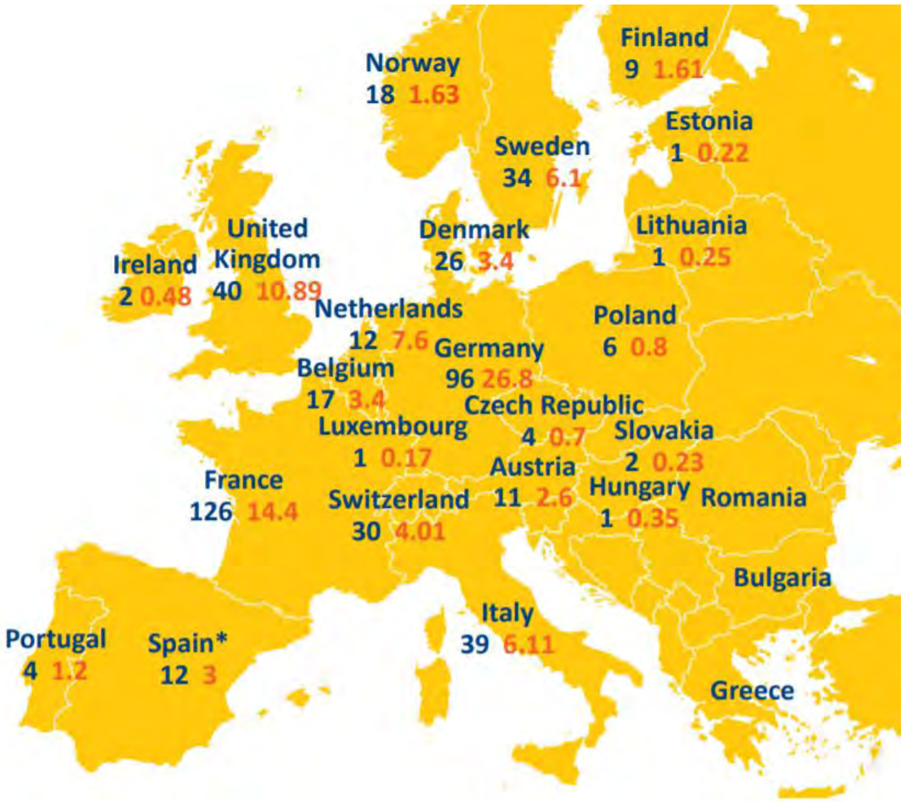


Figure 59: Waste-to-Energy in Europe in 2017 (with red: waste thermally treated (in million tonnes) and with blue: plants operating in Europe) (CEWEP, 2017)

The necessary treatment that is to be used depends highly on the nature and volume of the waste stream with the main factor taken into account its energy content (calorific value) and as a rule of thumb waste-to-energy option should be considered when the incoming waste has an average calorific value of at least 7 MJ/kg (World Energy Council, 2016).

Table 35 presents the average net calorific values for most common MSW waste streams.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Table 35: Approximate net calorific value (MJ/kg) (ISWA, 2013)

Fraction	Value
Paper	16
Organic material	4
Plastics	35
Glass	0
Metals	0
Textiles	19
Other material	11

Overall the European Commission recommends the main technologies that could be used (Malinauskaite et al., 2017):

- co-incineration in combustion plants: with gasification of SRF and co-incineration of the resulting syngas in the combustion plant.
- co-incineration in cement kilns.
- incineration in dedicated facilities:
    - the use of super heaters and heat pumps
    - the utilisation of the energy contained in flue gas
    - distributing chilled water through district cooling networks.
- bio-methane for further distribution and utilisation.

In those regards Scarlat et al. (2018) perform a suitability analysis as to where waste-to-energy plants are best to be built, which can be seen graphically on Figure 60. The potential plants (shown in green) are interrelated with the results of the current analysis, as according to their analysis, there is great potential to build plants for instance in Czech Republic, Croatia, France, Hungary, Italy, Spain and UK.

For those countries the current analysis found that energy efficiency scores are overall quite low in comparison to other countries. Also Greece and Bulgaria show a great potential for building

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

waste-to-energy plants which makes sense according to this analysis as for these countries efficiency scores are quite low as well.

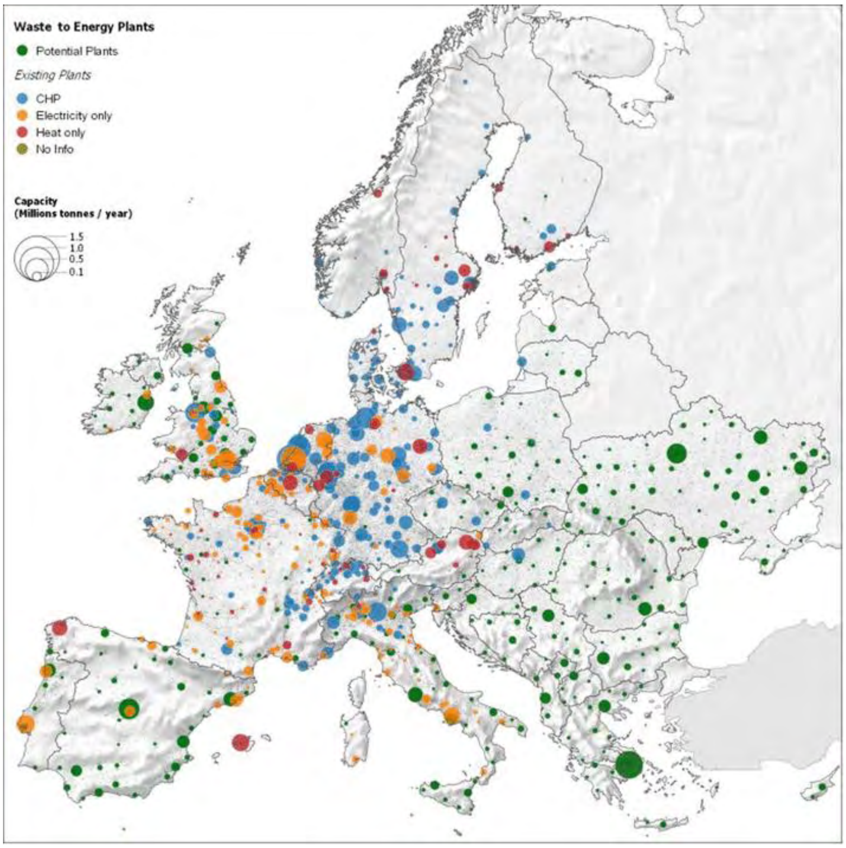


Figure 60: Suitability map for waste-to-energy plant location (Scarlat et al., 2018)

Energy efficiency levels across the 28 EU examined countries are quite low overall with only a few countries differentiating. As it stands, waste management holds a crucial part in the context of the circular economy whereas prioritization needs to be given to prevention, preparation for reuse, recycling and energy recovery through to disposal, such as landfilling (European Commission, 2015a). The circular economy aims to accomplish the optimum production through the 3R principle – reduce, reuse and recycle – while minimizing resource utilization, pollution emissions and waste discarded (Wu et al., 2014).

Therefore the treatment options employed by EU Member States are very much related to the European Commission's Circular Economy Package, which aims to accelerate Europe's transition towards a circular economy by certain legislative proposals, along with the waste reduction targets across EU Member States (European Commission, 2016a). To do so, the value of products, materials and resources needs to be maintained in the economy for as long as possible and the generation of waste minimized (European Commission, 2015b). Hence waste to energy addresses the problems of energy demand, waste management and GHG emissions at the same time, achieving a circular economy system (Trindade et al., 2018). By 2020 196 billion kWh of sustainable energy could be produced through waste-to-energy plants which makes an equivalent of the energy produced by 6-9 nuclear stations or 25 coal power plants (Kleppmann, 2013).

At the same time one of the EU Commission's priorities is also a European Energy Union which ensures reliable energy supplies at rational prices for businesses and consumers and with the least environmental impacts (European Commission, 2012b). This union would enhance the economy and attract investments thus creating new jobs opportunities (European Commission, 2017b). Competition policy in the EU is essential for the internal market with the first liberalisation directives established in 1996 (electricity) and 1998 (gas) and the second liberalisation directives adopted in 2003 (European Commission, 2012b). This competition policy aims mainly to ensure that companies compete fairly, creating a wider choice for consumers and helping reduce prices and improve quality (European Commission, 2015c).

Despite these regulations, markets seem to be largely national and with relatively few cross-border trade, therefore the EU Commission has paid great attention into controlling potential mergers (such as the proposed merger between EDP and GDP in Portugal), into setting up rules for mergers and in controlling state aid to energy companies across the EU (European Commission, 2012b). In more detail, it is essential to have an EU competition policy, mainly to achieve (European Commission, 2015c):

- Low prices for all: thus more people can afford to buy products and businesses are encouraged to produce.
- Better quality: competition encourages businesses to improve the quality of goods and services they sell and to attract more customers and expand their market share.

- More choice: businesses will try to make their products unique.
- Innovation: in their product concepts, design, production techniques, services, etc.
- Better competitors in global markets: competition would enhance European companies' strength outside the EU and enable them to hold their own against global competitors.

Also waste-to-energy could relief the EU from foreign imports, for instance in 2012 it imported 4 million TJ of natural gas from Russia, whereas waste-to-energy could substitute 19% of Russian gas imports (Kleppmann, 2013). Unfair competition will hinder the clean energy transition as far as Member States continue to provide fossil fuel subsidies, such as direct subsidies to uneconomical coal mines, capacity mechanisms for emission intensive power plants, tax relief for company cars or diesel fuel and similar measures (European Commission, 2017b).

One important and unexpected issue that needs to be taken into account and has undoubtedly affected energy efficiency in EU Member States is the financial crisis from which the EU has suffered severely after 2008. This can also be noticed in the efficiency scores obtained through the present analysis, whereas efficiencies have decreased after 2012 when the crisis became more imminent.

As for the future steps, the EU plans for a climate-neutral Europe by 2050 through investments to realistic technological solutions, the empowering of citizens and aligning action in key areas such as industrial policy, finance, or research (European Commission, 2018). In those regards studies suggest that the potential for using heat from waste could be an equivalent to 200 billion kWh per year by 2050 (Kleppmann, 2013). Therefore it is essential to already arrange meetings with young people, citizens affected by the energy transition, inventors, social partners and civil society, mayors and other politicians to provide positive examples of how the energy transition is achievable in practice (European Commission, 2017b).

5.5 Panel data results analysis (OECD countries)

The present analysis' empirical findings indicate the existence of an inverted U-shaped curve in both cases of the OECD and EU countries. A number of possible explanations exist for this inverted U-shape relationship. EKC may be decomposed into three effects: scale of economic activity, structure

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

of the production and income effect on demand and supply of mitigation efforts (Panayotou, 1997). Specifically, natural progression of economic growth goes from clean agricultural to polluting industrial and to clean service economies (Dinda, 2004).

Some studies have evaluated the factors which cause an inverted U-shape pattern which include among others the following:

- Improvement in environmental quality due to changes in the technological mode of production (de Bruyn, 1997; Han and Chatterjee, 1997).
- Role of preferences and regulation on emissions (Lopez, 1994; McConnell, 1997; Stokey, 1998).

Furthermore the inverted U-shape in the present analysis can be explained by the fact that demand for environmental quality increases with income (Halkos, 2011b), hence in this case leading to lower MSW arisings with income increase. Overall a more organised institutional background through property rights, regulations and good governance can raise public awareness against environmental damages (Dinda et al., 2000).

At the same time the increasing size of the economy through trade and exports leads to stricter regulations to reduce pollution which may increase due to scale effects (Halkos, 2011b). Also environmental damage increases linearly with income until a certain point is reached in which cleaner technologies can be employed (Stokey, 1998).

By accepting the EKC hypothesis in this analysis, one also accepts that there is an unavoidable level of environmental degradation following a country's development at earlier stages, followed by significant progress at later stages of a country's economic development (Aydin and Esen, 2017). Overall a government's willingness to impose and establish environmental regulations is essential to increase environmental quality (Panayotou, 1997). Kaika and Zervas (2013) stress that as an economy grows, governments need to respond quickly to raise public awareness and overcome market failures by imposing appropriate regulations. However this process can be time consuming, hence not desired by many governments but is key in reducing environmental degradation (Dasgupta et al., 2002).

The present analysis' results also illustrate that accepting the presence of an EKC, seems as a temporary phenomenon and it is suggested to seek ways to stimulate sustainable growth in the form of stricter regulations, price reforms and economic restructuring. In Figure 61 the upper curve refers to the dynamic while the lower one to the static specifications of the analysis' results.

GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

A part of the steepness of the inverted U-shaped relationship between economic growth and MSW may be due to policy distortions. Governments can flatten out their EKC by reducing or eliminating these policy distortions, defining and applying stricter regulations of waste treatment and internalizing environmental costs to sources generating them (Wu et al., 2018).

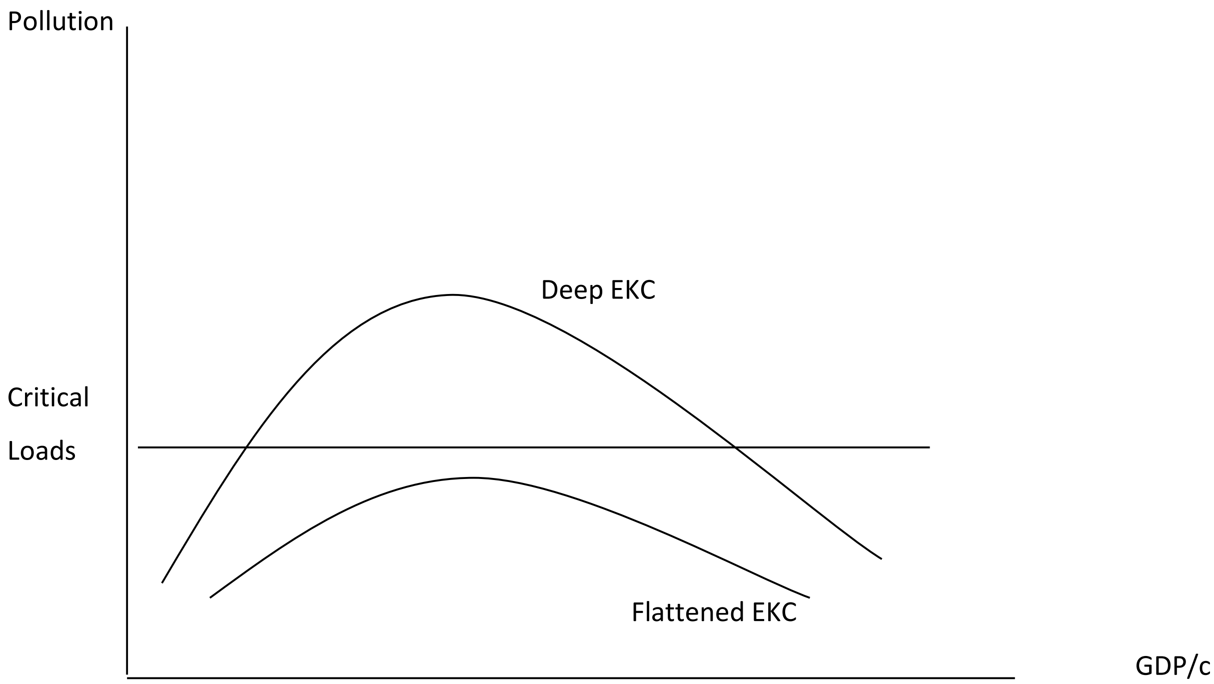


Figure 61: Environmental Kuznets Curve and critical loads

As mentioned some of the steepness of an inverted U-shaped relationship can be explained by various policy distortions, as current regulations seem to bring with them complexities and distortions leading to efficiency losses (Nicolaisen et al., 1991). At the same time moving towards more sustainable waste management options such as recycling may bring with it direct and indirect costs which need to be accounted for, such as (Næss-Schmidt and Jensen, 2015):

- Net production cost.
- Potential environmental damages.
- Potential impact on public revenue (labour market distortion).
- Impact on product markets from higher recycling rates (product market distortion).

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

As it stands all policy measures can cause market distortions. Table 36 presents the main policy instrument categories and the associated implications for product and labour market distortions.

Table 36: Policy measures and distortions (Adapted from Næss-Schmidt and Jensen, 2015)

Environmental policy measures	Labour market distortion	Product market distortion
Command and Control	(√)	√
Environmental taxes		√
Support new technologies	√	√
User fees		√

To address these market distortions, Table 37 presents some relevant macroeconomic level interventions that could be undertaken (Rentschler et al., 2018).

Table 37: Complementary policy measures and interventions (Adapted from Rentschler et al., 2018)

	Technical assistance and policy reform	Development lending
Addressing the symptoms of market distortions	➢ Building strategies for greater material recovery from waste.	
Addressing the structural causes	➢ Institution building. ➢ Fiscal policy reforms. ➢ Legal requirements for monitoring. ➢ Strengthening of financial sector. ➢ More competition.	➢ Developing markets and infrastructure. ➢ Strengthen macro-economy. ➢ Institution building. ➢ Direct support of Research and Innovation. ➢ Green growth strategies.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

It needs to be pointed out that an EKC is the result of structural change that follows economic growth, but may not be optimal if environmental critical loads are crossed permanently. The positively sloped part of an EKC may last for a long time, which means that present value of higher future growth may be balanced by high current rates of environmental degradation; also it may be cheaper to abate today than in the future (Halkos, 2003). All these points should be taken into account by policy makers worldwide.

Overall Section 5 discussed the main findings of the Thesis analysis and aimed at identifying the potential policy implications of each case. Of course as the data and methodology used were different the results themselves cannot be contrasted, but it is apparent that the current financial and political situation both in EU and worldwide has affected the development of the MSW sector and people's attitudes as well. This was evident through all approaches whether the focus was on MSW itself or cultural dimensions or energy efficiency or even education.

The following and last section (Section 6) will summarise the main points of the Thesis as well as outline the limitations of this study and potential areas for future research.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

6. Conclusions

This Section summarises the main points that were raised through the various parts of the current research in Section 6.1, whereas Section 6.2 outlines the limitations of the Thesis as well as areas for future research.

6.1 Summary of the main points raised

This sub section summarises the main points for all analyses. As mentioned already, the aim of this Thesis was to identify the current situation of MSW arisings and their management under the notion of the circular economy. In achieving this aim the following objectives have been met as well:

- Assessment of current situation regarding MSW management and relevant environmental efficiency.
- Identification of existing and potential waste management options.
- The results of this analysis were analysed taking the financial crisis into consideration and possible societal and policy implications.
- Suggestions were provided for the fulfilment of a real circular economy in EU Member States in accordance to the EU regulations and programmes, as well as potential policy implications for worldwide data.

In more detail Section 6.1.1 summarises the main points around the EU regional level analysis, Section 6.1.2 the EU country level analysis, Section 6.1.3 deals with the cultural dimensions and EU countries analysis, Section 6.1.4 with energy efficiency for EU countries and finally Section 6.1.5 with the OECD country analysis.

6.1.1 DEA EU regional level anaylsis

This analysis focused on the efficiency of 172 EU regions for the years 2009, 2011 and 2013 by employing DEA analysis and by using five parameters, namely waste generation, employment rate, capital formation, GDP and population density for the relevant regions. Therefore four frameworks were designed, each with different inputs and outputs.

Overall results show that the highest performers are regions in Belgium, Italy, Portugal and the UK. The efficiency results from DEA were reviewed against the treatment options employed in the relevant regions.

This demonstrated that, although high performers generally employ a mix of all treatment options, landfill is still in extensive use in these regions. This can be attributed to the fact that, although waste is produced in the region, it may actually be treated elsewhere. Therefore, although a country might be efficient according to DEA and by taking many factors into consideration, this does not necessarily mean that this region uses sustainable waste treatment options, as it is essential to account for the trade of waste between regions and countries as well.

6.1.2 DEA EU country level analysis

This part of the Thesis dealt with the efficiency of 28 EU Member States for the years 2008, 2010, 2012 and 2014. For this, it employs DEA and uses eight parameters, namely waste generation, employment rate, capital formation, GDP, population density and for the first time SOx, NOx and GHG emissions for the relevant countries. The obtained results present the more efficient EU countries according to each framework, but it should be stressed once again that results from different frameworks should not be compared to each other due to the different inputs/outputs used.

These results were then reviewed against the recycling rate of each country for the examined period. The recycling rate actually depicts the DEA results, namely more efficient countries seem to have higher recycling rates too. Moreover the DEA efficiency results were compared to overall treatment options used in the countries in question.

Germany is efficient under all DEA frameworks and is actually one of the countries in EU with the most incineration, material recycling and composting of waste and treats only a small amount of waste at landfills. France, Italy, the Netherlands and Spain and Sweden employ all treatment options with Sweden almost without any landfill treated waste, at the same time Sweden is efficient in all DEA frameworks too. The surprising result is the UK which is efficient under all frameworks but still highly relies on landfill for the year 2008, but this decreases with the passing of time.

Overall it is noticed that countries which employ all four treatment options with high use of more sustainable ones and decrease in the use of landfill are the ones that also proved to be efficient according to DEA and under a circular economy approach. This can be a valuable tool for policy makers

GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

in the design and application of national and EU legislations and directives in order to achieve also the targets towards a circular economy driven Europe until 2020 and 2030.

6.1.3 DEA cultural dimensions and waste culture (EU countries)

This analysis evaluated environmental efficiency with DEA based on the following five parameters: waste, GDP, labour, capital, and population density for 22 EU Member States and for the years 2005, 2010 and 2015 in order to evaluate which Member States are more efficient. It showed that overall Denmark, Greece, Italy, Netherlands and Poland are efficient under both designed frameworks. Then the results from the efficiency analysis are contrasted to Hofstede's and Schwartz's cultural dimensions with the use of regression modelling.

Results show that for year 2005 no significant relationship is noticed between the efficiency scores and the cultural dimensions' data from both researchers (R^2 shows a low predictability indicating that only a small percentage of variation in efficiency scores is explained and the p-value of the F-stat indicates no significant overall statistical relationship between the variables), whereas for years 2010 and 2015 there appears to be a significant connection with changes in the predictors also affecting the response variable.

Among Hofstede's dimensions, individualism, uncertainty avoidance, long-term orientation and indulgence were positively associated with the efficiency scores regarding waste arisings for 2010 and 2015. The relationship between Schwartz's cultural values and the DEA efficiency scores was not found to be significant. Findings suggest that Hofstede's cultural dimensions would be best to be considered when developing national level strategies and campaigns to manage waste arisings.

These findings can also be associated with the financial crisis that has hit Europe after 2008 making people more sceptical on environmental issues and how waste is best to be managed making sense financially but also environmentally.

At the same time, EU legislations have laid out some important Directives in the field of waste management. Finally, along with the factors above, EU has been faced with severe environmental challenges due to waste arisings, as well as accidents and injuries for people working in this sector. All these factors have widely modified waste culture and public's approach toward waste as represented by the Thesis' results as well.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

6.1.4 DEA and energy efficiency (EU countries)

The current analysis examined energy efficiency across 28 selected EU Member States and reviews the potential for energy recovery from waste according to the efficiency scores obtained for the examined Member States. The efficiencies were assessed through DEA under CRS and the following variables are examined: final energy consumption, GDP, labour, capital, population density, NOx emissions (from energy), SOx emissions (from energy) and GHG emissions (from energy) from Eurostat data and for the years 2008, 2010, 2012, 2014 and 2016. The two models that were designed use two outputs one desirable (GDP) and one undesirable (aerial gas emissions – GHG, SOx and NOx) with different inputs in each case.

The bias corrected efficiency scores show that overall Bulgaria, Cyprus, Estonia, Greece, Lithuania and Slovenia are efficient under both frameworks. Also most countries seem to maintain their efficiency scores with only Czech Republic, Finland, Ireland, Malta, Romania and Slovenia marginally improving theirs. At the same time, it can be noticed that most countries have higher environmental efficiency scores over 2010 and 2012 with a decrease after those years.

These efficiency scores show that EU wise environmental efficiency levels regarding energy consumption and emissions tend to be quite low overall, therefore it is suggestible to move towards waste-to-energy with two main objectives, namely sufficient and sustainable energy production and effective treatment of MSW. This option would enhance the circular economy, whereas prioritization needs to give to prevention, preparation for reuse, recycling and energy recovery through to disposal, such as landfilling. Waste to energy tackles the problems of energy demand, waste management and GHG emissions simultaneously.

Together with the EU Commission's competition strategy, these options would ensure reliable energy supplies at rational prices for businesses and consumers and with the least environmental impacts. Along with these and taking into account the current analysis' results, it is essential to account for the financial crisis which affects EU since 2008. Namely the efficiency scores show a decrease after 2012 when the crisis became more imminent. Regarding future steps towards a climate neutral Europe, investments into technology along with the empowering of citizens and industry need to be considered.

GSRT
GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I.
Hellenic Foundation for Research & Innovation

6.1.5 Panel data analysis (OECD countries)

The last part of this Thesis used panel data obtained for 25 world counties for the years 1995-2016 and the examined variables included MSW, GDP and education level. The contribution of this analysis is twofold. First, it strongly accounts for the presence of cross section dependence and uses appropriate panel unit root tests to discover feasible cointegrated relationships especially in the existing limited literature concerning MSW. Secondly, it is strongly accounted for the interdependence between MSW, economic growth and education level.

From the empirical perspective the validity of the EKC hypothesis is redefined by accounting for the presence of education. Moreover, it is evident that the shape of the relationship between growth and financial development on environmental degradation remains robust. Specifically, an inverted U-shape relationship is observed both in the static and dynamic analyses for MSW. The calculated turning points although quite high they are in all cases within the sample. The adjustment coefficients are very low ranging equal to 0.113 and 0.142. In all specifications the sign of education level is negative as expected.

Based on this analysis education is shown to be able to act as an effective tool to enhance pro-environmental behaviours leading to lower MSW arisings. Thus environmental education should be a fundamental and integral part of education. Modern societies, both developed and developing, need environmental education in their formal and informal aspects.

6.2 Limitations of Thesis & suggestions for future research

One limitation of this Thesis is that the models generated among the different approaches cannot be compared to each other due to conceptual as well as methodological reasons. Specifically for the DEA models, one such reason is that in some models 'bad' outputs are modelled as 'good' outputs and in other models 'bad' outputs are modelled as inputs. Also results of the different models cannot be compared as the number of inputs/outputs in all models is not equal. Therefore as expected the average efficiency is higher in models with more inputs/outputs.

Moreover another limitation of this Thesis' DEA analysis is the sample size, which may be representative for the EU total but would benefit with the addition of countries worldwide to get more robust results. More specifically for the waste culture analysis and cultural dimensions, this analysis used these two models (Hofstede and Schwartz) due to lack of data for further models as the ones mentioned briefly in Section 2.6. If data from other models were made available, further implications of this research could be drawn. Findings of this research though could form the basis for further work on the topic and more data could be analysed as well to enhance this approach.

Moreover regarding the OECD panel data analysis the models of the present research could be enriched with additional control variables which could incorporate specific characteristics of EU countries, such as their technological level regarding waste management especially and their institutional background to name a few.

Also although the results of this analysis show evidence of an EKC, further analysis should be conducted with the addition of more countries due to the high turning points which are nevertheless within the examined income range. Moreover it would be beneficial to also conduct this research with regional data which would allow more in-depth analysis and could account for the heterogeneity among the examined countries.

Finally this Thesis would benefit from the collection of primary data through questionnaires to the public and potential interviews with relevant stakeholders to gain a better understanding of the current situation. Once data become available it would be useful to expand this research with more recent data to better reflect today's conditions.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Appendix 1

Table 1.1:Results of M1, M2, M3 and M4 framework for 17 countries for 2009, 2011 and 2013

	M1			M2			M3			M4		
Region	**2009**	**2011**	**2013**	**2009**	**2011**	**2013**	**2009**	**2011**	**2013**	**2009**	**2011**	**2013**
Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.187	0.193	0.199
Prov. Antwerpen	0.690	0.698	0.695	0.729	0.710	0.731	0.784	0.781	0.761	0.188	0.195	0.206
Prov. Limburg (BE)	0.660	0.646	0.602	0.631	0.602	0.634	0.686	0.664	0.665	0.062	0.065	0.068
Prov. Oost-Vlaanderen	0.643	0.644	0.572	0.659	0.621	0.600	0.704	0.698	0.634	0.120	0.123	0.130
Prov. Vlaams-Brabant	0.809	0.704	0.672	0.805	0.682	0.701	0.879	0.795	0.744	0.107	0.107	0.116
Prov. West-Vlaanderen	0.628	0.611	0.567	0.634	0.583	0.594	0.682	0.662	0.631	0.102	0.104	0.110
Prov. Brabant Wallon	0.795	0.724	0.608	0.805	0.696	0.643	0.853	0.778	0.675	0.078	0.080	0.075
Prov. Hainaut	0.776	0.763	0.709	0.744	0.698	0.722	0.788	0.768	0.758	0.079	0.081	0.084
Prov. Liège	0.784	0.689	0.664	0.763	0.648	0.698	0.835	0.717	0.736	0.073	0.075	0.078
Prov. Luxembourg (BE)	0.866	0.733	0.567	0.828	0.650	0.585	0.873	0.725	0.738	0.029	0.031	0.034
Prov. Namur	0.715	0.666	0.665	0.698	0.659	0.690	0.770	0.725	0.768	0.043	0.044	0.045
Severozapaden	1.000	1.000	0.804	1.000	1.000	0.661	1.000	1.000	1.000	0.008	0.008	0.008
Severen tsentralen	1.000	0.974	1.000	0.975	0.868	0.817	0.975	0.868	1.000	0.009	0.009	0.009
Severoiztochen	0.849	0.768	1.000	0.487	0.604	0.672	0.517	0.661	0.789	0.012	0.012	0.013
Yugoiztochen	0.749	0.877	0.920	0.439	0.583	0.414	0.508	0.705	0.517	0.013	0.013	0.014
Yugozapadna i yuzhna tsentralna Bulgaria	0.767	0.700	0.720	0.452	0.572	0.574	0.558	0.728	0.689	0.066	0.070	0.071
Yuzhen tsentralen	1.000	1.000	1.000	0.658	0.620	0.540	0.698	0.714	0.649	0.015	0.016	0.016
Praha	0.573	0.584	0.553	0.621	0.609	0.585	0.643	0.655	0.602	0.109	0.111	0.107
Strední Cechy	0.562	0.622	0.466	0.514	0.473	0.476	0.605	0.548	0.535	0.046	0.049	0.048
Jihozápad	0.552	0.573	0.516	0.532	0.538	0.565	0.686	0.759	0.688	0.043	0.045	0.044

Severozápad	0.583	0.511	0.492	0.563	0.452	0.496	0.626	0.524	0.539	0.037	0.037	0.035
Severovýchod	0.632	0.651	0.633	0.628	0.596	0.636	0.717	0.724	0.726	0.050	0.053	0.051
Jihovýchod	0.566	0.573	0.590	0.540	0.530	0.616	0.634	0.652	0.711	0.061	0.064	0.066
Strední Morava	0.590	0.618	0.591	0.541	0.565	0.601	0.613	0.639	0.655	0.040	0.042	0.041
Moravskoslezsko	0.592	0.575	0.525	0.553	0.529	0.538	0.606	0.562	0.560	0.041	0.045	0.042
Stuttgart	0.739	0.778	0.701	0.786	0.803	0.725	0.838	0.861	0.768	0.415	0.458	0.489
Karlsruhe	0.753	0.774	0.730	0.815	0.809	0.760	0.852	0.852	0.794	0.267	0.279	0.290
Freiburg	0.688	0.709	0.632	0.766	0.747	0.668	0.839	0.841	0.749	0.180	0.192	0.203
Tübingen	0.652	0.658	0.581	0.743	0.707	0.643	0.812	0.797	0.706	0.160	0.175	0.184
Oberbayern	0.737	0.686	0.638	0.751	0.698	0.665	0.906	0.926	0.947	0.530	0.563	0.613
Niederbayern	0.748	0.715	0.618	0.799	0.741	0.706	0.939	0.928	0.822	0.097	0.106	0.111
Oberpfalz	0.692	0.606	0.614	0.767	0.627	0.710	0.894	0.778	0.817	0.093	0.100	0.106
Oberfranken	0.796	0.738	0.699	0.780	0.721	0.739	0.899	0.875	0.839	0.084	0.088	0.092
Mittelfranken	0.654	0.623	0.584	0.707	0.646	0.624	0.766	0.718	0.679	0.160	0.166	0.177
Unterfranken	0.794	0.760	0.703	0.829	0.767	0.766	0.946	0.921	0.881	0.112	0.120	0.126
Schwaben	0.675	0.645	0.609	0.744	0.668	0.651	0.831	0.773	0.743	0.151	0.161	0.173
Berlin	0.829	0.897	0.770	0.870	0.905	0.798	0.870	0.905	0.798	0.285	0.295	0.311
Brandenburg	0.660	0.702	0.630	0.712	0.695	0.662	0.901	0.887	0.798	0.155	0.157	0.167
Bremen	1.000	0.960	0.820	1.000	0.969	0.928	1.000	0.969	0.928	0.073	0.076	0.081
Hamburg	0.726	0.768	0.708	0.814	0.800	0.761	0.835	0.830	0.771	0.263	0.261	0.276
Darmstadt	0.910	0.845	0.838	0.966	0.871	0.869	1.000	0.902	0.874	0.451	0.457	0.478
Gießen	0.797	0.652	0.659	0.788	0.642	0.726	0.877	0.730	0.758	0.080	0.082	0.085
Kassel	0.790	0.684	0.687	0.801	0.680	0.750	0.917	0.818	0.850	0.100	0.102	0.108
Mecklenburg-Vorpommern	0.656	0.596	0.599	0.690	0.585	0.648	0.902	0.778	0.802	0.099	0.099	0.103

Braunschweig	0.648	0.670	0.665	0.678	0.671	0.710	0.750	0.769	0.783	0.132	0.150	0.165
Hannover	0.851	0.839	0.736	0.848	0.819	0.762	0.910	0.917	0.835	0.180	0.187	0.196
Lüneburg	0.696	0.653	0.549	0.676	0.623	0.582	0.810	0.783	0.707	0.103	0.106	0.114
Weser-Ems	0.640	0.648	0.599	0.672	0.654	0.622	0.772	0.766	0.721	0.189	0.198	0.209
Düsseldorf	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.504	0.501	0.525
Köln	0.920	0.871	0.875	0.928	0.884	0.887	0.972	0.924	0.902	0.418	0.421	0.440
Münster	0.822	0.815	0.729	0.837	0.803	0.744	0.879	0.854	0.785	0.200	0.206	0.215
Detmold	0.810	0.810	0.785	0.875	0.826	0.846	0.919	0.882	0.875	0.173	0.179	0.190
Arnsberg	0.894	0.923	0.868	0.904	0.935	0.877	0.945	0.983	0.904	0.286	0.296	0.308
Koblenz	0.723	0.757	0.639	0.730	0.738	0.681	0.817	0.856	0.771	0.111	0.116	0.121
Trier	0.596	0.530	0.487	0.618	0.531	0.561	0.735	0.636	0.615	0.036	0.037	0.040
Rheinhessen-Pfalz	0.723	0.714	0.653	0.732	0.703	0.681	0.786	0.766	0.724	0.166	0.174	0.184
Saarland	0.964	0.804	0.739	0.940	0.780	0.797	1.000	0.826	0.820	0.083	0.087	0.090
Dresden	0.609	0.526	0.601	0.683	0.551	0.686	0.740	0.621	0.723	0.105	0.106	0.115
Chemnitz	0.694	0.655	0.655	0.767	0.666	0.743	0.835	0.724	0.767	0.091	0.094	0.097
Leipzig	0.705	0.643	0.579	0.773	0.687	0.684	0.872	0.687	0.701	0.067	0.070	0.078
Thüringen	0.628	0.677	0.640	0.676	0.679	0.672	0.780	0.830	0.793	0.131	0.139	0.146
Eesti	0.641	0.547	0.473	0.626	0.484	0.530	0.997	0.884	0.738	0.041	0.045	0.052
Piemonte	0.808	0.786	0.739	0.824	0.798	0.762	0.956	0.905	0.945	0.347	0.349	0.338
Valle d'Aosta/Vallée d'Aoste	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Liguria	1.000	1.000	1.000	0.885	0.771	0.998	0.912	0.889	1.000	0.135	0.130	0.125
Lombardia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.953	0.962	0.960
Nord-Est	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Provincia Autonoma di Bolzano/Bozen	0.682	0.591	0.573	0.674	0.593	0.618	0.813	0.760	0.714	0.053	0.054	0.057

Veneto	0.790	0.839	0.902	0.829	0.856	0.916	0.872	0.898	0.941	0.409	0.406	0.402
Friuli-Venezia Giulia	0.767	0.821	0.821	0.751	0.745	0.820	0.799	0.864	0.889	0.098	0.098	0.095
Emilia-Romagna	0.951	0.966	0.941	0.805	0.941	0.915	1.000	1.000	1.000	0.390	0.393	0.396
Toscana	1.000	1.000	0.963	0.924	0.931	0.967	1.000	1.000	1.000	0.300	0.293	0.298
Umbria	0.877	0.881	0.866	0.802	0.769	0.862	0.838	0.875	0.937	0.062	0.060	0.060
Marche	0.910	0.901	0.880	0.875	0.792	0.878	0.916	0.901	0.934	0.115	0.110	0.107
Lazio	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.525	0.511	0.502
Abruzzo	0.807	0.774	0.650	0.660	0.665	0.633	0.692	0.771	0.696	0.086	0.087	0.087
Molise	0.951	0.936	0.910	0.924	0.885	0.873	0.951	0.943	0.934	0.051	0.056	0.056
Campania	0.984	1.000	1.000	0.853	0.922	0.993	0.856	0.943	0.993	0.296	0.276	0.274
Puglia	0.932	0.926	0.907	0.777	0.810	0.898	0.812	0.875	0.920	0.198	0.194	0.196
Basilicata	0.849	0.846	0.938	0.817	0.762	0.880	0.850	0.863	0.949	0.034	0.038	0.038
Calabria	0.892	0.948	0.827	0.696	0.637	0.755	0.720	0.732	0.799	0.095	0.091	0.088
Sicilia	1.000	1.000	1.000	0.871	0.885	1.000	0.906	0.958	1.000	0.255	0.241	0.241
Sardegna	0.888	0.879	0.909	0.647	0.750	0.903	0.910	0.950	1.000	0.095	0.091	0.091
Latvija	0.716	0.730	0.575	0.597	0.555	0.534	0.910	0.978	0.780	0.054	0.055	0.063
Lietuva	1.000	1.000	0.885	0.750	0.693	0.662	1.000	1.000	0.936	0.078	0.085	0.096
Luxembourg	1.000	1.000	1.000	0.968	1.000	1.000	1.000	1.000	1.000	0.104	0.115	0.128
Közép-Magyarország	0.800	1.000	0.860	0.793	0.958	0.836	0.828	0.980	0.868	0.133	0.132	0.135
Nyugat-Dunántúl	0.979	0.893	0.480	0.648	0.527	0.477	0.714	0.596	0.568	0.025	0.028	0.028
Dél-Dunántúl	1.000	0.849	0.550	0.512	0.548	0.485	0.562	0.632	0.623	0.018	0.017	0.018
Észak-Magyarország	0.999	0.808	0.664	0.682	0.548	0.524	0.741	0.605	0.603	0.020	0.020	0.020
Észak-Alföld	0.787	0.817	0.932	0.566	0.542	0.477	0.615	0.667	0.548	0.026	0.026	0.027
Dél-Alföld	1.000	0.753	0.559	0.608	0.531	0.510	0.672	0.634	0.655	0.024	0.024	0.025

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Malta	0.854	0.716	0.731	0.993	0.771	0.707	0.993	0.771	0.707	0.018	0.020	0.021
Groningen	0.827	1.000	0.778	0.865	1.000	0.901	0.967	1.000	0.916	0.076	0.080	0.090
Friesland (NL)	0.608	0.702	0.728	0.592	0.628	0.722	0.652	0.662	0.747	0.049	0.049	0.050
Drenthe	0.687	0.749	0.759	0.667	0.695	0.746	0.726	0.705	0.773	0.038	0.036	0.038
Overijssel	0.627	0.645	0.703	0.691	0.653	0.762	0.727	0.661	0.767	0.100	0.099	0.098
Gelderland	0.680	0.702	0.690	0.620	0.641	0.661	0.655	0.679	0.691	0.181	0.179	0.179
Flevoland	0.478	0.437	0.484	0.545	0.490	0.580	0.585	0.490	0.590	0.037	0.046	0.044
Utrecht	0.689	0.701	0.694	0.776	0.732	0.791	0.792	0.747	0.791	0.160	0.153	0.157
Noord-Holland	0.768	0.885	0.896	0.852	0.931	0.933	0.856	0.931	0.933	0.348	0.344	0.358
Zuid-Holland	0.726	0.725	0.771	0.757	0.748	0.795	0.757	0.748	0.795	0.389	0.371	0.380
Zeeland	0.535	0.531	0.530	0.504	0.497	0.575	0.586	0.524	0.597	0.030	0.031	0.031
Zuid-Nederland	0.693	0.778	0.762	0.778	0.836	0.810	1.000	1.000	1.000	0.355	0.359	0.366
Limburg (NL)	0.665	0.713	0.668	0.699	0.706	0.734	0.729	0.713	0.734	0.097	0.097	0.098
Wien	0.719	0.727	0.695	0.743	0.729	0.729	0.749	0.738	0.732	0.218	0.218	0.229
Kärnten	0.740	0.643	0.587	0.767	0.626	0.666	1.000	0.881	0.820	0.046	0.047	0.049
Steiermark	0.661	0.639	0.577	0.703	0.646	0.641	0.898	0.847	0.787	0.105	0.107	0.114
Oberösterreich	0.658	0.710	0.626	0.716	0.720	0.669	0.843	0.889	0.802	0.138	0.143	0.152
Salzburg	0.659	0.640	0.575	0.676	0.660	0.671	0.849	0.862	0.786	0.059	0.062	0.066
Tirol	0.630	0.583	0.535	0.641	0.592	0.614	0.870	0.830	0.756	0.072	0.073	0.080
Vorarlberg	0.755	0.725	0.600	0.994	0.938	0.751	1.000	0.938	0.787	0.095	0.087	0.080
Lódzkie	0.790	0.771	0.655	0.638	0.563	0.565	0.711	0.686	0.667	0.055	0.063	0.066
Mazowieckie	0.831	0.885	0.777	0.678	0.785	0.758	0.810	0.949	0.909	0.192	0.225	0.241
Malopolskie	0.846	0.821	0.731	0.714	0.632	0.642	0.734	0.705	0.700	0.069	0.080	0.084
Slaskie	1.000	0.908	0.890	0.657	0.702	0.706	0.675	0.734	0.729	0.117	0.134	0.136

Lubelskie	0.697	0.645	0.652	0.691	0.514	0.596	0.776	0.697	0.748	0.035	0.041	0.043
Podkarpackie	0.651	0.532	0.560	0.680	0.435	0.525	0.704	0.560	0.606	0.035	0.040	0.043
Swietokrzyskie	0.619	0.568	0.723	0.730	0.601	0.768	0.769	0.692	0.883	0.024	0.028	0.032
Podlaskie	0.673	0.595	0.634	0.726	0.467	0.583	0.829	0.697	0.784	0.021	0.024	0.025
Wielkopolskie	0.857	0.823	0.833	0.696	0.675	0.713	0.840	0.846	0.866	0.087	0.097	0.105
Zachodniopomorskie	0.802	0.836	0.637	0.659	0.636	0.541	0.766	0.815	0.642	0.035	0.039	0.041
Lubuskie	0.768	0.569	0.683	0.788	0.457	0.626	0.821	0.575	0.776	0.021	0.023	0.024
Dolnoslaskie	0.829	0.852	0.691	0.627	0.671	0.649	0.727	0.813	0.742	0.075	0.089	0.092
Opolskie	0.683	0.688	0.690	0.778	0.639	0.645	0.800	0.702	0.756	0.020	0.022	0.023
Kujawsko-Pomorskie	0.680	0.741	0.787	0.575	0.551	0.678	0.644	0.698	0.776	0.041	0.046	0.049
Warminsko-Mazurskie	0.688	0.672	0.701	0.696	0.495	0.625	0.830	0.706	0.810	0.025	0.028	0.029
Pomorskie	0.629	0.779	0.715	0.468	0.593	0.627	0.544	0.739	0.714	0.052	0.059	0.062
Norte	0.869	0.927	0.869	0.630	0.726	0.762	0.750	0.860	0.844	0.142	0.136	0.136
Algarve	1.000	1.000	1.000	0.662	0.729	0.891	0.717	0.810	1.000	0.021	0.020	0.020
Centro (PT)	0.758	0.914	0.916	0.658	0.761	0.865	0.817	0.978	1.000	0.095	0.090	0.089
Área Metropolitana de Lisboa	0.906	1.000	1.000	0.837	0.939	1.000	0.838	0.959	1.000	0.191	0.180	0.173
Alentejo	0.739	0.690	0.760	0.612	0.544	0.714	0.929	1.000	1.000	0.033	0.031	0.030
Região Autónoma dos Açores (PT)	0.937	1.000	0.859	1.000	1.000	0.839	1.000	1.000	1.000	0.026	0.021	0.030
Região Autónoma da Madeira (PT)	0.874	0.907	1.000	0.828	0.896	1.000	0.828	0.896	1.000	0.022	0.042	0.051
Bratislavský kraj	0.764	0.562	0.484	0.759	0.536	0.502	0.862	0.618	0.530	0.052	0.053	0.057
Západné Slovensko	0.711	0.762	0.821	0.657	0.634	0.787	0.748	0.769	0.877	0.059	0.062	0.065
Stredné Slovensko	0.670	0.621	0.766	0.665	0.535	0.741	0.757	0.722	0.924	0.037	0.038	0.040
Východné Slovensko	0.586	0.684	0.843	0.614	0.594	0.820	0.685	0.749	0.953	0.036	0.039	0.041
Tees Valley and Durham	0.799	0.783	0.711	0.762	0.681	0.693	0.766	0.681	0.696	0.063	0.065	0.071

Northumberland and Tyne and Wear	0.845	0.827	0.721	0.828	0.772	0.714	0.832	0.818	0.745	0.084	0.089	0.097
Cumbria	0.895	0.757	0.757	0.966	0.732	0.787	1.000	0.965	0.982	0.032	0.033	0.038
Greater Manchester	1.000	1.000	1.000	0.974	0.986	1.000	0.974	0.986	1.000	0.177	0.179	0.203
Lancashire	0.924	1.000	0.886	0.916	0.940	0.873	0.916	0.940	0.896	0.086	0.088	0.099
East Yorkshire and Northern Lincolnshire	0.939	0.943	0.736	0.964	0.876	0.724	0.980	0.876	0.737	0.061	0.058	0.062
North Yorkshire	0.823	0.885	0.826	0.831	0.835	0.829	0.943	1.000	1.000	0.055	0.058	0.064
South Yorkshire	0.806	0.814	0.770	0.826	0.774	0.791	0.826	0.774	0.791	0.074	0.076	0.083
West Yorkshire	0.977	0.993	0.871	0.971	0.978	0.878	0.971	0.978	0.878	0.149	0.153	0.167
Derbyshire and Nottinghamshire	0.869	0.911	0.765	0.809	0.862	0.766	0.809	0.862	0.769	0.125	0.137	0.151
Leicestershire, Rutland and Northamptonshire	0.757	0.906	0.794	0.746	0.885	0.817	0.772	0.885	0.823	0.115	0.121	0.135
Lincolnshire	0.637	0.652	0.662	0.645	0.586	0.696	0.721	0.745	0.772	0.039	0.042	0.048
Herefordshire, Worcestershire and Warwickshire	0.859	0.794	0.718	0.851	0.758	0.750	0.869	0.816	0.794	0.083	0.091	0.103
Shropshire and Staffordshire	0.974	0.896	0.761	0.960	0.838	0.753	0.960	0.888	0.795	0.089	0.096	0.105
West Midlands	0.924	0.985	0.972	0.848	0.948	0.971	0.848	0.948	0.971	0.167	0.177	0.197
East Anglia	0.649	0.730	0.656	0.664	0.740	0.678	0.751	0.870	0.800	0.167	0.178	0.197
Bedfordshire and Hertfordshire	0.935	0.912	0.812	0.954	0.899	0.853	0.975	0.906	0.867	0.141	0.142	0.159
Essex	0.920	0.903	0.868	0.928	0.874	0.868	0.929	0.874	0.877	0.109	0.115	0.124
Berkshire, Buckinghamshire and Oxfordshire	0.807	0.885	0.823	0.877	0.915	0.862	0.909	0.951	0.884	0.229	0.249	0.280
Surrey, East and West Sussex	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.215	0.225	0.261
Hampshire and Isle of Wight	0.647	0.746	0.755	0.712	0.769	0.805	0.730	0.778	0.806	0.146	0.156	0.174
Kent	0.876	0.824	0.921	0.870	0.781	0.917	0.870	0.781	0.943	0.106	0.113	0.125
Gloucestershire, Wiltshire and Bristol/Bath area	0.852	0.848	0.753	0.887	0.852	0.779	0.951	0.930	0.850	0.187	0.196	0.216
Dorset and Somerset	0.893	0.855	0.765	0.909	0.821	0.774	0.924	0.903	0.828	0.082	0.085	0.093
Cornwall and Isles of Scilly	0.742	0.682	0.693	0.784	0.640	0.692	0.813	0.659	0.735	0.029	0.030	0.034

Devon	0.877	0.809	0.676	0.896	0.739	0.699	0.927	0.856	0.769	0.069	0.071	0.080
West Wales and The Valleys	0.943	0.894	0.723	0.830	0.764	0.663	0.954	0.923	0.801	0.094	0.098	0.109
East Wales	0.854	0.792	0.727	0.861	0.732	0.743	0.938	0.885	0.850	0.073	0.077	0.085
Eastern Scotland	0.742	0.880	0.713	0.692	0.798	0.707	0.861	1.000	0.890	0.148	0.147	0.163
South Western Scotland	0.842	0.794	0.635	0.718	0.720	0.623	0.865	0.858	0.744	0.155	0.154	0.168
North Eastern Scotland	0.764	0.359	0.315	0.814	0.403	0.361	1.000	0.510	0.565	0.052	0.056	0.064
Highlands and Islands	0.710	0.526	0.429	0.613	0.462	0.461	1.000	1.000	1.000	0.031	0.032	0.035
Northern Ireland (UK)	0.586	0.781	0.676	0.537	0.713	0.680	0.628	0.866	0.815	0.109	0.112	0.122
Average	**0.789**	**0.778**	**0.736**	**0.758**	**0.722**	**0.731**	**0.830**	**0.816**	**0.808**	**0.135**	**0.138**	**0.144**

Table 1.2: Average scores of each region for all the years per framework

	M1	M2	M3	M4
Region	**Average**	**Average**	**Average**	**Average**
Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	1.000	1.000	1.000	0.193
Prov. Antwerpen	0.694	0.723	0.775	0.196
Prov. Limburg (BE)	0.636	0.622	0.672	0.065
Prov. Oost-Vlaanderen	0.620	0.627	0.679	0.125
Prov. Vlaams-Brabant	0.729	0.729	0.806	0.110
Prov. West-Vlaanderen	0.602	0.604	0.658	0.105
Prov. Brabant Wallon	0.709	0.715	0.769	0.078
Prov. Hainaut	0.749	0.721	0.772	0.081
Prov. Liège	0.712	0.703	0.763	0.075
Prov. Luxembourg (BE)	0.722	0.687	0.779	0.032
Prov. Namur	0.682	0.682	0.754	0.044
Severozapaden	0.935	0.887	1.000	0.008
Severen tsentralen	0.991	0.887	0.948	0.009
Severoiztochen	0.872	0.587	0.656	0.012
Yugoiztochen	0.848	0.479	0.577	0.014
Yugozapadna i yuzhna tsentralna Bulgaria	0.729	0.533	0.658	0.069
Yuzhen tsentralen	1.000	0.606	0.687	0.016
Praha	0.570	0.605	0.634	0.109
Strední Cechy	0.550	0.488	0.563	0.047
Jihozápad	0.547	0.545	0.711	0.044
Severozápad	0.528	0.503	0.563	0.036
Severovýchod	0.638	0.620	0.722	0.051
Jihovýchod	0.576	0.562	0.666	0.064
Strední Morava	0.600	0.569	0.636	0.041
Moravskoslezsko	0.564	0.540	0.576	0.043
Stuttgart	0.740	0.771	0.822	0.454
Karlsruhe	0.752	0.794	0.833	0.279
Freiburg	0.676	0.727	0.810	0.191
Tübingen	0.630	0.698	0.772	0.173
Oberbayern	0.687	0.705	0.926	0.569
Niederbayern	0.694	0.748	0.896	0.104
Oberpfalz	0.637	0.701	0.829	0.099
Oberfranken	0.744	0.747	0.871	0.088
Mittelfranken	0.620	0.659	0.721	0.168
Unterfranken	0.752	0.787	0.916	0.119
Schwaben	0.643	0.688	0.782	0.162
Berlin	0.832	0.857	0.857	0.297
Brandenburg	0.664	0.689	0.862	0.160

Bremen	0.927	0.965	0.965	0.077
Hamburg	0.734	0.792	0.812	0.267
Darmstadt	0.864	0.902	0.925	0.462
Gießen	0.703	0.719	0.789	0.083
Kassel	0.720	0.744	0.862	0.103
Mecklenburg-Vorpommern	0.617	0.641	0.827	0.101
Braunschweig	0.661	0.686	0.767	0.149
Hannover	0.808	0.810	0.887	0.188
Lüneburg	0.633	0.627	0.767	0.108
Weser-Ems	0.629	0.649	0.753	0.199
Düsseldorf	1.000	1.000	1.000	0.510
Köln	0.889	0.900	0.932	0.426
Münster	0.788	0.795	0.839	0.207
Detmold	0.801	0.849	0.892	0.181
Arnsberg	0.895	0.905	0.944	0.297
Koblenz	0.706	0.716	0.815	0.116
Trier	0.538	0.570	0.662	0.037
Rheinhessen-Pfalz	0.697	0.705	0.758	0.175
Saarland	0.836	0.839	0.882	0.087
Dresden	0.579	0.640	0.695	0.109
Chemnitz	0.668	0.725	0.775	0.094
Leipzig	0.642	0.715	0.753	0.072
Thüringen	0.649	0.676	0.801	0.138
Eesti	0.553	0.547	0.873	0.046
Piemonte	0.778	0.795	0.936	0.345
Valle d'Aosta/Vallée d'Aoste	1.000	1.000	1.000	1.000
Liguria	1.000	0.884	0.933	0.130
Lombardia	1.000	1.000	1.000	0.958
Nord-Est	1.000	1.000	1.000	1.000
Provincia Autonoma di Bolzano/Bozen	0.616	0.629	0.763	0.055
Veneto	0.844	0.867	0.904	0.406
Friuli-Venezia Giulia	0.803	0.772	0.851	0.097
Emilia-Romagna	0.953	0.887	1.000	0.393
Toscana	0.988	0.941	1.000	0.297
Umbria	0.875	0.811	0.883	0.061
Marche	0.897	0.849	0.917	0.111
Lazio	1.000	1.000	1.000	0.513
Abruzzo	0.744	0.653	0.720	0.087
Molise	0.932	0.894	0.943	0.054
Campania	0.995	0.923	0.931	0.282

Puglia	0.922	0.828	0.869	0.196
Basilicata	0.877	0.819	0.887	0.036
Calabria	0.889	0.696	0.750	0.091
Sicilia	1.000	0.919	0.955	0.246
Sardegna	0.892	0.767	0.954	0.093
Latvija	0.674	0.562	0.889	0.057
Lietuva	0.962	0.702	0.979	0.086
Luxembourg	1.000	0.989	1.000	0.116
Közép-Magyarország	0.887	0.863	0.892	0.133
Nyugat-Dunántúl	0.784	0.551	0.626	0.027
Dél-Dunántúl	0.800	0.515	0.606	0.018
Észak-Magyarország	0.824	0.585	0.650	0.020
Észak-Alföld	0.845	0.528	0.610	0.026
Dél-Alföld	0.771	0.549	0.654	0.024
Malta	0.767	0.824	0.824	0.020
Groningen	0.868	0.922	0.961	0.082
Friesland (NL)	0.679	0.647	0.687	0.049
Drenthe	0.732	0.702	0.735	0.037
Overijssel	0.658	0.702	0.718	0.099
Gelderland	0.691	0.640	0.675	0.180
Flevoland	0.466	0.539	0.555	0.042
Utrecht	0.694	0.766	0.777	0.157
Noord-Holland	0.850	0.906	0.907	0.350
Zuid-Holland	0.741	0.766	0.767	0.380
Zeeland	0.532	0.525	0.569	0.031
Zuid-Nederland	0.745	0.808	1.000	0.360
Limburg (NL)	0.682	0.713	0.726	0.097
Wien	0.713	0.734	0.739	0.221
Kärnten	0.657	0.686	0.900	0.047
Steiermark	0.626	0.663	0.844	0.108
Oberösterreich	0.665	0.701	0.845	0.144
Salzburg	0.625	0.669	0.832	0.062
Tirol	0.583	0.615	0.819	0.075
Vorarlberg	0.693	0.894	0.909	0.087
Lódzkie	0.739	0.589	0.688	0.062
Mazowieckie	0.831	0.740	0.890	0.219
Malopolskie	0.800	0.663	0.713	0.078
Slaskie	0.932	0.688	0.713	0.129
Lubelskie	0.665	0.600	0.740	0.040
Podkarpackie	0.581	0.546	0.623	0.039

Swietokrzyskie	0.636	0.700	0.781	0.028
Podlaskie	0.634	+0.592	0.770	0.023
Wielkopolskie	0.838	0.694	0.851	0.096
Zachodniopomorskie	0.758	0.612	0.741	0.038
Lubuskie	0.673	0.624	0.724	0.022
Dolnoslaskie	0.791	0.649	0.761	0.085
Opolskie	0.687	0.687	0.753	0.022
Kujawsko-Pomorskie	0.736	0.601	0.706	0.045
Warminsko-Mazurskie	0.687	0.605	0.782	0.027
Pomorskie	0.708	0.563	0.666	0.058
Norte	0.888	0.706	0.818	0.138
Algarve	1.000	0.761	0.843	0.020
Centro (PT)	0.863	0.761	0.932	0.091
Área Metropolitana de Lisboa	0.969	0.926	0.932	0.181
Alentejo	0.729	0.623	0.976	0.031
Região Autónoma dos Açores (PT)	0.932	0.946	1.000	0.026
Região Autónoma da Madeira (PT)	0.927	0.9F08	0.908	0.038
Bratislavský kraj	0.603	0.599	0.670	0.054
Západné Slovensko	0.765	0.693	0.798	0.062
Stredné Slovensko	0.686	0.647	0.801	0.038
Východné Slovensko	0.705	0.676	0.796	0.039
Tees Valley and Durham	0.765	0.712	0.714	0.067
Northumberland and Tyne and Wear	0.798	0.772	0.798	0.090
Cumbria	0.803	0.828	0.983	0.034
Greater Manchester	1.000	0.986	0.986	0.186
Lancashire	0.937	0.910	0.917	0.091
East Yorkshire and Northern Lincolnshire	0.872	0.855	0.864	0.060
North Yorkshire	0.844	0.832	0.981	0.059
South Yorkshire	0.797	0.797	0.797	0.078
West Yorkshire	0.947	0.943	0.943	0.156
Derbyshire and Nottinghamshire	0.848	0.812	0.813	0.138
Leicestershire, Rutland and Northamptonshire	0.819	0.816	0.827	0.123
Lincolnshire	0.650	0.642	0.746	0.043
Herefordshire, Worcestershire and Warwickshire	0.790	0.786	0.826	0.092
Shropshire and Staffordshire	0.877	0.850	0.881	0.097
West Midlands	0.960	0.922	0.922	0.180
East Anglia	0.678	0.694	0.807	0.181
Bedfordshire and Hertfordshire	0.886	0.902	0.916	0.147
Essex	0.897	0.890	0.893	0.116
Berkshire, Buckinghamshire and Oxfordshire	0.839	0.885	0.915	0.253

Surrey, East and West Sussex	1.000	1.000	1.000	0.234
Hampshire and Isle of Wight	0.716	0.762	0.771	0.159
Kent	0.874	0.856	0.865	0.115
Gloucestershire, Wiltshire and Bristol/Bath area	0.817	0.840	0.910	0.200
Dorset and Somerset	0.837	0.835	0.885	0.086
Cornwall and Isles of Scilly	0.706	0.705	0.735	0.031
Devon	0.787	0.778	0.851	0.073
West Wales and The Valleys	0.853	0.752	0.893	0.100
East Wales	0.791	0.779	0.891	0.078
Eastern Scotland	0.778	0.732	0.917	0.153
South Western Scotland	0.757	0.687	0.822	0.159
North Eastern Scotland	0.479	0.526	0.691	0.057
Highlands and Islands	0.555	0.512	1.000	0.032
Northern Ireland (UK)	0.681	0.643	0.770	0.114

Table 1.3: Descriptive statistics of regions' environmental efficiency estimates grouped by country

Belgium (11 regions)		**2009**	**2011**	**2013**	**Bulgaria (6 regions)**		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.761	0.716	0.666	**Model 1-M1**	*mean*	0.894	0.886	0.907
	std	0.110	0.104	0.122		*std*	0.121	0.128	0.120
	min	0.628	0.611	0.567		*min*	0.749	0.700	0.720
	max	1.000	1.000	1.000		*max*	1.000	1.000	1.000
Model 2-M2	*mean*	0.754	0.686	0.691	**Model 2-M2**	*mean*	0.668	0.708	0.613
	std	0.107	0.112	0.115		*std*	0.260	0.181	0.137
	min	0.631	0.583	0.585		*min*	0.439	0.572	0.414
	max	1.000	1.000	1.000		*max*	1.000	1.000	0.817
Model 3-M3	*mean*	0.805	0.756	0.737	**Model 3-M3**	*mean*	0.709	0.779	0.774
	std	0.096	0.093	0.101		*std*	0.226	0.129	0.196
	min	0.682	0.662	0.631		*min*	0.508	0.661	0.517
	max	1.000	1.000	1.000		*max*	1.000	1.000	1.000
Model 4 -M4	*mean*	0.097	0.100	0.104	**Model 4 -M4**	*mean*	0.020	0.021	0.022
	std	0.052	0.053	0.057		*std*	0.022	0.024	0.024
	min	0.029	0.031	0.034		*min*	0.008	0.008	0.008
	max	0.188	0.195	0.206		*max*	0.066	0.070	0.071

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Czech Republic (8 regions)		2009	2011	2013
Model 1-M1	*mean*	0.581	0.588	0.546
	std	0.025	0.042	0.056
	min	0.552	0.511	0.466
	max	0.632	0.651	0.633
Model 2-M2	*mean*	0.561	0.536	0.564
	std	0.042	0.055	0.057
	min	0.514	0.452	0.476
	max	0.628	0.609	0.636
Model 3-M3	*mean*	0.641	0.633	0.627
	std	0.040	0.084	0.078
	min	0.605	0.524	0.535
	max	0.717	0.759	0.726
Model 4 -M4	*mean*	0.053	0.056	0.054
	std	0.024	0.024	0.023
	min	0.037	0.037	0.035
	max	0.109	0.111	0.107

Germany (36 regions)		2009	2011	2013
Model 1-M1	*mean*	0.756	0.731	0.684
	std	0.109	0.113	0.104
	min	0.596	0.526	0.487
	max	1.000	1.000	1.000
Model 2-M2	*mean*	0.791	0.740	0.732
	std	0.097	0.113	0.096
	min	0.618	0.531	0.561
	max	1.000	1.000	1.000
Model 3-M3	*mean*	0.871	0.831	0.799
	std	0.077	0.092	0.081
	min	0.735	0.621	0.615
	max	1.000	1.000	1.000
Model 4 -M4	*mean*	0.187	0.195	0.206
	std	0.129	0.133	0.142
	min	0.036	0.037	0.040
	max	0.530	0.563	0.613

Italy (21 regions)		2009	2011	2013
Model 1-M1	*mean*	0.909	0.909	0.896
	std	0.095	0.106	0.119
	min	0.682	0.591	0.573
	max	1.000	1.000	1.000
Model 2-M2	*mean*	0.839	0.834	0.889
	std	0.113	0.123	0.116
	min	0.647	0.593	0.618
	max	1.000	1.000	1.000
Model 3-M3	*mean*	0.895	0.911	0.936
	std	0.094	0.082	0.092
	min	0.692	0.732	0.696
	max	1.000	1.000	1.000
Model 4 -M4	*mean*	0.309	0.307	0.305
	std	0.314	0.315	0.315

Hungary (6 regions)		2009	2011	2013
Model 1-M1	*mean*	0.928	0.853	0.674
	std	0.104	0.086	0.183
	min	0.787	0.753	0.480
	max	1.000	1.000	0.932
Model 2-M2	*mean*	0.635	0.609	0.551
	std	0.098	0.171	0.141
	min	0.512	0.527	0.477
	max	0.793	0.958	0.836
Model 3-M3	*mean*	0.689	0.686	0.644
	std	0.094	0.146	0.116
	min	0.562	0.596	0.548
	max	0.828	0.980	0.868
Model 4 -M4	*mean*	0.041	0.041	0.042
	std	0.045	0.045	0.045

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

	min	0.034	0.038	0.038
	max	1.000	1.000	1.000

	min	0.018	0.017	0.018
	max	0.133	0.132	0.135

Netherlands (12 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.665	0.714	0.705
	std	0.095	0.145	0.110
	min	0.478	0.437	0.484
	max	0.827	1.000	0.896
Model 2-M2	*mean*	0.695	0.713	0.751
	std	0.116	0.154	0.110
	min	0.504	0.490	0.575
	max	0.865	1.000	0.933
Model 3-M3	*mean*	0.753	0.738	0.778
	std	0.134	0.165	0.125
	min	0.585	0.490	0.590
	max	1.000	1.000	1.000
Model 4 -M4	*mean*	0.155	0.154	0.157
	std	0.135	0.131	0.135
	min	0.030	0.031	0.031
	max	0.389	0.371	0.380

Austria (7 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.689	0.667	0.599
	std	0.048	0.055	0.050
	min	0.630	0.583	0.535
	max	0.755	0.727	0.695
Model 2-M2	*mean*	0.748	0.701	0.677
	std	0.116	0.115	0.048
	min	0.641	0.592	0.614
	max	0.994	0.938	0.751
Model 3-M3	*mean*	0.887	0.855	0.782
	std	0.090	0.062	0.029
	min	0.749	0.738	0.732
	max	1.000	0.938	0.820
Model 4 -M4	*mean*	0.105	0.105	0.110
	std	0.059	0.059	0.062
	min	0.046	0.047	0.049
	max	0.218	0.218	0.229

Poland (16 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.753	0.730	0.710
	std	0.105	0.122	0.082
	min	0.619	0.532	0.560
	max	1.000	0.908	0.890
Model 2-M2	*mean*	0.675	0.589	0.641
	std	0.077	0.098	0.071
	min	0.468	0.435	0.525
	max	0.788	0.785	0.768
Model 3-M3	*mean*	0.749	0.726	0.757
	std	0.080	0.096	0.084
	min	0.544	0.560	0.606

Portugal (7 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.869	0.920	0.915
	std	0.094	0.110	0.092
	min	0.739	0.690	0.760
	max	1.000	1.000	1.000
Model 2-M2	*mean*	0.747	0.799	0.867
	std	0.145	0.156	0.109
	min	0.612	0.544	0.714
	max	1.000	1.000	1.000
Model 3-M3	*mean*	0.840	0.929	0.978
	std	0.098	0.075	0.059
	min	0.717	0.810	0.844

	max	0.840	0.949	0.909		*max*	1.000	1.000	1.000
Model 4 -M4	*mean*	0.057	0.065	0.068	**Model 4 -M4**	*mean*	0.076	0.074	0.076
	std	0.046	0.053	0.056		*std*	0.068	0.063	0.060
	min	0.020	0.022	0.023		*min*	0.021	0.020	0.020
	max	0.192	0.225	0.241		*max*	0.191	0.180	0.173

Slovakia (4 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.683	0.657	0.729
	std	0.075	0.086	0.166
	min	0.586	0.562	0.484
	max	0.764	0.762	0.843
Model 2-M2	*mean*	0.674	0.575	0.713
	std	0.061	0.048	0.144
	min	0.614	0.535	0.502
	max	0.759	0.634	0.820
Model 3-M3	*mean*	0.763	0.715	0.821
	std	0.073	0.067	0.196
	min	0.685	0.618	0.530
	max	0.862	0.769	0.953
Model 4 -M4	*mean*	0.046	0.048	0.051
	std	0.011	0.012	0.012
	min	0.036	0.038	0.040
	max	0.059	0.062	0.065

UK (33 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.838	0.829	0.754
	std	0.109	0.136	0.138
	min	0.586	0.359	0.315
	max	1.000	1.000	1.000
Model 2-M2	*mean*	0.831	0.790	0.764
	std	0.116	0.136	0.133
	min	0.537	0.403	0.361
	max	1.000	1.000	1.000
Model 3-M3	*mean*	0.885	0.870	0.839
	std	0.096	0.110	0.101
	min	0.628	0.510	0.565
	max	1.000	1.000	1.000
Model 4 -M4	*mean*	0.107	0.112	0.125
	std	0.054	0.057	0.064
	min	0.029	0.030	0.034
	max	0.229	0.249	0.280

Table 1.4: Efficiency scores of M1, M2 and M3 frameworks for the EU countries for 2008, 2010, 2012 and 2014

Country	M1				M2				M3			
	2008	2010	2012	2014	2008	2010	2012	2014	2008	2010	2012	2014
Austria	0.868	0.779	0.815	0.504	0.910	0.801	0.838	0.527	0.931	0.944	0.985	0.565
Belgium	0.862	0.811	0.805	0.503	0.902	0.836	0.814	0.514	0.898	0.875	0.908	0.510
Bulgaria	0.541	0.544	0.561	0.501	0.551	0.544	0.561	0.545	0.614	0.642	0.591	0.584
Cyprus	0.677	0.672	0.822	0.502	0.681	0.672	0.822	1.000	1.000	1.000	1.000	1.000
Czech Republic	0.658	0.637	0.663	0.560	0.681	0.664	0.678	0.583	0.592	0.572	0.587	0.556
Denmark	0.901	0.857	0.865	0.526	0.957	0.865	0.865	0.551	0.948	0.943	0.959	0.598
Estonia	0.618	0.643	0.627	0.502	0.633	0.643	0.636	1.000	1.000	1.000	1.000	1.000
Finland	0.926	0.875	0.903	0.506	0.983	0.972	1.000	1.000	1.000	1.000	1.000	1.000
France	0.834	0.785	0.793	0.503	1.000	1.000	1.000	0.506	1.000	1.000	1.000	0.507
Germany	0.932	0.851	0.866	0.504	1.000	0.981	1.000	0.505	1.000	1.000	1.000	0.522
Greece	0.793	0.768	1.000	0.502	0.825	0.768	1.000	0.526	1.000	1.000	1.000	1.000
Hungary	0.696	0.709	0.768	1.000	0.698	0.709	0.768	1.000	0.832	0.790	0.746	1.000
Ireland	0.933	1.000	1.000	0.506	0.998	1.000	1.000	0.588	1.000	1.000	1.000	0.554
Italy	0.817	0.775	0.854	0.502	0.864	0.843	0.902	0.504	0.957	0.961	0.955	0.505
Latvia	0.604	0.612	0.551	0.502	0.608	0.612	0.554	0.757	1.000	1.000	1.000	1.000
Lithuania	0.616	0.715	0.689	0.501	0.622	0.715	0.689	0.625	1.000	1.000	1.000	0.972
Luxembourg	1.000	1.000	1.000	0.509	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Malta	0.798	0.702	0.756	0.502	0.798	0.702	0.756	1.000	1.000	1.000	1.000	1.000
Netherlands	0.841	0.812	0.854	0.504	0.868	0.813	0.854	0.510	1.000	1.000	1.000	0.528
Norway	0.975	0.935	0.906	0.505	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Poland	0.749	0.713	0.744	0.509	0.772	0.716	0.744	0.520	0.743	0.776	0.766	0.510
Portugal	0.719	0.697	0.877	0.502	0.722	0.697	0.877	0.522	0.858	0.795	0.855	0.509

Romania	0.562	0.565	0.588	0.508	0.565	0.573	0.597	0.535	0.501	0.546	0.552	0.516
Slovakia	0.643	0.633	0.655	0.502	0.657	0.638	0.655	0.563	0.680	0.627	0.661	0.559
Slovenia	0.707	0.730	0.806	0.503	0.732	0.730	0.806	0.766	0.805	0.878	0.939	0.845
Spain	0.694	0.708	0.794	0.502	0.764	0.836	0.964	0.507	0.928	0.907	1.000	0.511
Sweden	0.852	0.830	0.838	0.543	0.959	0.972	0.999	1.000	0.978	0.986	1.000	1.000
United Kingdom	1.000	1.000	1.000	0.503	1.000	1.000	1.000	0.505	1.000	1.000	1.000	0.506

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Table 1.5: Average efficiency scores per country and per modelling framework

Country	M1	M2	M3
Austria	0.741	0.769	0.856
Belgium	0.745	0.766	0.798
Bulgaria	0.537	0.550	0.608
Cyprus	0.668	0.794	1.000
Czech Republic	0.629	0.652	0.577
Denmark	0.787	0.810	0.862
Estonia	0.597	0.728	1.000
Finland	0.802	0.989	1.000
France	0.729	0.877	0.877
Germany	0.788	0.871	0.880
Greece	0.766	0.779	1.000
Hungary	0.793	0.794	0.842
Ireland	0.860	0.897	0.888
Italy	0.737	0.779	0.845
Latvia	0.567	0.633	1.000
Lithuania	0.630	0.663	0.993
Luxembourg	0.877	1.000	1.000
Malta	0.690	0.814	1.000
Netherlands	0.753	0.761	0.882
Norway	0.830	1.000	1.000
Poland	0.679	0.688	0.699
Portugal	0.699	0.705	0.754
Romania	0.556	0.568	0.529
Slovakia	0.608	0.628	0.632
Slovenia	0.687	0.758	0.867
Spain	0.675	0.768	0.837
Sweden	0.766	0.983	0.991
United Kingdom	0.876	0.876	0.876

Table 1.6: Biased corrected efficiency scores of countries' by modelling framework

Framework M1

Country	Efficiency scores	Bias corrected	bias	std	lower	upper	2008	Country	Efficiency scores	Bias corrected	bias	std	lower	upper	2010
Austria	0.868	0.800	0.068	0.034	0.757	0.885		Austria	0.779	0.695	0.085	0.040	0.641	0.785	
Belgium	0.862	0.788	0.074	0.038	0.738	0.882		Belgium	0.811	0.716	0.095	0.043	0.658	0.808	
Bulgaria	0.541	0.527	0.014	0.006	0.519	0.541		Bulgaria	0.544	0.515	0.029	0.018	0.495	0.556	
Cyprus	0.677	0.639	0.039	0.018	0.614	0.684		Cyprus	0.672	0.617	0.055	0.027	0.578	0.683	
Czech Republic	0.658	0.620	0.038	0.023	0.590	0.668		Czech Republic	0.637	0.585	0.051	0.028	0.544	0.632	
Denmark	0.901	0.820	0.081	0.043	0.760	0.923		Denmark	0.857	0.747	0.110	0.054	0.670	0.866	
Estonia	0.618	0.589	0.030	0.018	0.565	0.626		Estonia	0.643	0.594	0.049	0.022	0.563	0.656	
Finland	0.926	0.832	0.094	0.059	0.758	0.961		Finland	0.875	0.744	0.131	0.071	0.642	0.872	
France	0.834	0.760	0.074	0.036	0.709	0.845		France	0.785	0.698	0.088	0.041	0.640	0.785	
Germany	0.932	0.837	0.095	0.044	0.769	0.935		Germany	0.851	0.754	0.097	0.046	0.683	0.862	
Greece	0.793	0.738	0.054	0.025	0.703	0.797		Greece	0.768	0.643	0.125	0.059	0.544	0.769	
Hungary	0.696	0.624	0.071	0.038	0.573	0.707		Hungary	0.709	0.625	0.084	0.039	0.566	0.704	
Ireland	0.933	0.825	0.108	0.061	0.738	0.946		Ireland	1.000	0.856	0.144	0.062	0.747	0.994	
Italy	0.817	0.693	0.124	0.051	0.601	0.800		Italy	0.775	0.670	0.105	0.048	0.603	0.783	
Latvia	0.604	0.582	0.022	0.014	0.564	0.613		Latvia	0.612	0.560	0.051	0.025	0.527	0.615	
Lithuania	0.616	0.580	0.036	0.018	0.554	0.617		Lithuania	0.715	0.609	0.106	0.050	0.531	0.699	
Luxembourg	1.000	0.667	0.333	0.250	0.359	1.191		Luxemboburg	1.000	0.650	0.350	0.209	0.337	1.090	
Malta	0.798	0.680	0.119	0.062	0.586	0.801		Malta	0.702	0.640	0.062	0.028	0.599	0.709	

Netherlands	0.841	0.768	0.073	0.036	0.717	0.845
Norway	0.975	0.827	0.148	0.088	0.702	1.003
Poland	0.749	0.698	0.051	0.021	0.665	0.746
Portugal	0.719	0.635	0.084	0.045	0.572	0.727
Romania	0.562	0.549	0.013	0.009	0.538	0.568
Slovakia	0.643	0.611	0.032	0.014	0.591	0.641
Slovenia	0.707	0.657	0.050	0.023	0.624	0.712
Spain	0.694	0.651	0.043	0.021	0.623	0.705
Sweden	0.852	0.782	0.069	0.036	0.734	0.877
United Kingdom	1.000	0.801	0.199	0.086	0.646	0.962

Country	**Efficiency scores**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2012**
Austria	0.815	0.741	0.073	0.035	0.694	0.821	
Belgium	0.805	0.723	0.082	0.038	0.669	0.809	
Bulgaria	0.561	0.540	0.021	0.011	0.525	0.565	
Cyprus	0.822	0.732	0.090	0.037	0.670	0.807	
Czech Republic	0.663	0.621	0.042	0.020	0.595	0.665	
Denmark	0.865	0.772	0.093	0.049	0.704	0.890	
Estonia	0.627	0.592	0.034	0.016	0.571	0.629	
Finland	0.903	0.806	0.097	0.050	0.733	0.914	

Netherlands	0.812	0.718	0.094	0.044	0.651	0.820
Norway	0.935	0.750	0.186	0.095	0.594	0.946
Poland	0.713	0.643	0.070	0.030	0.603	0.719
Portugal	0.697	0.610	0.087	0.041	0.548	0.712
Romania	0.565	0.540	0.024	0.011	0.526	0.565
Slovakia	0.633	0.591	0.042	0.019	0.565	0.635
Slovenia	0.730	0.664	0.066	0.030	0.617	0.738
Spain	0.708	0.643	0.065	0.032	0.598	0.720
Sweden	0.830	0.722	0.108	0.053	0.647	0.809
United Kingdom	1.000	0.793	0.207	0.084	0.627	0.967

Country	**Efficiency scores**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2014**
Austria	0.504	0.494	0.010	0.003	0.485	0.497	
Belgium	0.503	0.494	0.009	0.002	0.486	0.497	
Bulgaria	0.501	0.498	0.004	0.001	0.494	0.499	
Cyprus	0.502	0.497	0.005	0.001	0.492	0.498	
Czech Republic	0.560	0.397	0.163	0.042	0.243	0.449	
Denmark	0.526	0.455	0.071	0.018	0.388	0.478	
Estonia	0.502	0.497	0.005	0.001	0.492	0.498	
Finland	0.506	0.490	0.016	0.004	0.475	0.495	

France	0.793	0.710	0.082	0.041	0.650	0.804
Germany	0.866	0.782	0.084	0.038	0.728	0.875
Greece	1.000	0.815	0.185	0.083	0.653	0.955
Hungary	0.768	0.700	0.067	0.028	0.661	0.760
Ireland	1.000	0.872	0.128	0.061	0.775	0.998
Italy	0.854	0.768	0.086	0.042	0.711	0.870
Latvia	0.551	0.536	0.015	0.008	0.527	0.554
Lithuania	0.689	0.631	0.058	0.027	0.596	0.687
Luxembourg	1.000	0.732	0.267	0.175	0.498	1.115
Malta	0.756	0.689	0.067	0.029	0.640	0.749
Netherlands	0.854	0.767	0.087	0.039	0.709	0.856
Norway	0.906	0.761	0.146	0.084	0.643	0.926
Poland	0.744	0.683	0.061	0.027	0.639	0.744
Portugal	0.877	0.769	0.108	0.051	0.691	0.867
Romania	0.588	0.563	0.025	0.012	0.548	0.590
Slovakia	0.655	0.610	0.045	0.019	0.582	0.652
Slovenia	0.806	0.740	0.066	0.028	0.698	0.809
Spain	0.794	0.711	0.082	0.038	0.653	0.788
Sweden	0.838	0.751	0.086	0.040	0.692	0.841
United Kingdom	1.000	0.876	0.124	0.054	0.776	0.974

France	0.503	0.494	0.009	0.002	0.485	0.497
Germany	0.504	0.494	0.010	0.003	0.485	0.497
Greece	0.502	0.497	0.005	0.001	0.492	0.498
Hungary	1.000	-0.383	1.383	0.345	-1.699	0.024
Ireland	0.506	0.490	0.016	0.004	0.475	0.495
Italy	0.502	0.496	0.007	0.002	0.489	0.498
Latvia	0.502	0.497	0.004	0.001	0.494	0.499
Lithuania	0.501	0.498	0.004	0.001	0.494	0.499
Luxembourg	0.509	0.484	0.025	0.007	0.460	0.492
Malta	0.502	0.496	0.007	0.002	0.489	0.498
Netherlands	0.504	0.494	0.010	0.002	0.485	0.497
Norway	0.505	0.491	0.014	0.004	0.478	0.496
Poland	0.509	0.484	0.026	0.007	0.460	0.492
Portugal	0.502	0.497	0.005	0.001	0.493	0.499
Romania	0.508	0.486	0.021	0.006	0.466	0.493
Slovakia	0.502	0.497	0.005	0.001	0.491	0.498
Slovenia	0.503	0.495	0.008	0.002	0.487	0.497
Spain	0.502	0.496	0.006	0.002	0.490	0.498
Sweden	0.543	0.427	0.116	0.030	0.317	0.464
United Kingdom	0.503	0.495	0.008	0.002	0.487	0.497

Framework M2

Country	Efficiency scores	Bias corrected	bias	std	lower	upper	2008	Country	Efficiency scores	Bias corrected	bias	std	lower	upper	2010
Austria	0.910	0.836	0.074	0.035	0.786	0.906		**Austria**	0.801	0.700	0.101	0.049	0.633	0.792	
Belgium	0.902	0.834	0.067	0.036	0.788	0.925		**Belgium**	0.836	0.751	0.085	0.048	0.690	0.878	
Bulgaria	0.551	0.540	0.011	0.005	0.534	0.551		**Bulgaria**	0.544	0.523	0.021	0.013	0.510	0.557	
Cyprus	0.681	0.637	0.045	0.017	0.608	0.675		**Cyprus**	0.672	0.626	0.047	0.025	0.590	0.691	
Czech Republic	0.681	0.646	0.035	0.018	0.623	0.687		**Czech Republic**	0.664	0.620	0.044	0.021	0.594	0.676	
Denmark	0.957	0.883	0.075	0.041	0.831	0.993		**Denmark**	0.865	0.759	0.106	0.066	0.678	0.916	
Estonia	0.633	0.604	0.029	0.012	0.588	0.630		**Estonia**	0.643	0.601	0.042	0.018	0.573	0.646	
Finland	0.983	0.852	0.131	0.101	0.747	1.072		**Finland**	0.972	0.824	0.147	0.104	0.702	1.055	
France	1.000	0.825	0.175	0.115	0.683	1.113		**France**	1.000	0.798	0.202	0.122	0.623	1.086	
Germany	1.000	0.875	0.125	0.082	0.768	1.101		**Germany**	0.981	0.849	0.131	0.079	0.737	1.071	
Greece	0.825	0.768	0.056	0.026	0.735	0.832		**Greece**	0.768	0.662	0.106	0.065	0.576	0.795	
Hungary	0.698	0.631	0.067	0.040	0.575	0.728		**Hungary**	0.709	0.644	0.065	0.035	0.598	0.719	
Ireland	0.998	0.885	0.114	0.071	0.792	1.064		**Ireland**	1.000	0.842	0.158	0.085	0.705	0.999	
Italy	0.864	0.734	0.130	0.083	0.630	0.932		**Italy**	0.843	0.705	0.139	0.079	0.593	0.902	
Latvia	0.608	0.582	0.026	0.013	0.565	0.611		**Latvia**	0.612	0.573	0.039	0.019	0.550	0.619	
Lithuania	0.622	0.588	0.034	0.016	0.564	0.628		**Lithuania**	0.715	0.638	0.077	0.044	0.578	0.734	
Luxembourg	1.000	0.711	0.289	0.257	0.447	1.272		**Luxembourg**	1.000	0.700	0.300	0.233	0.430	1.174	
Malta	0.798	0.704	0.094	0.059	0.625	0.849		**Malta**	0.702	0.650	0.051	0.024	0.616	0.715	

Netherlands	0.868	0.796	0.072	0.036	0.746	0.877	
Norway	1.000	0.691	0.309	0.198	0.415	1.027	
Poland	0.772	0.720	0.052	0.024	0.687	0.784	
Portugal	0.722	0.638	0.083	0.053	0.567	0.758	
Romania	0.565	0.549	0.016	0.009	0.537	0.574	
Slovakia	0.657	0.628	0.029	0.011	0.612	0.655	
Slovenia	0.732	0.689	0.042	0.017	0.665	0.726	
Spain	0.764	0.683	0.081	0.057	0.622	0.836	
Sweden	0.959	0.841	0.119	0.084	0.743	1.084	
United Kingdom	1.000	0.775	0.225	0.144	0.572	1.077	
Country	**Efficiency scores**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2012**
Austria	0.838	0.753	0.085	0.044	0.692	0.846	
Belgium	0.814	0.739	0.075	0.044	0.683	0.840	
Bulgaria	0.561	0.542	0.019	0.009	0.530	0.562	
Cyprus	0.822	0.754	0.067	0.036	0.705	0.838	
Czech Republic	0.678	0.641	0.037	0.017	0.617	0.676	
Denmark	0.865	0.775	0.089	0.061	0.703	0.904	
Estonia	0.636	0.607	0.029	0.013	0.588	0.635	
Finland	1.000	0.882	0.118	0.076	0.784	1.042	

Netherlands	0.813	0.728	0.085	0.050	0.662	0.838	
Norway	1.000	0.663	0.337	0.193	0.362	1.008	
Poland	0.716	0.636	0.080	0.040	0.587	0.744	
Portugal	0.697	0.626	0.071	0.040	0.576	0.723	
Romania	0.573	0.552	0.022	0.011	0.538	0.578	
Slovakia	0.638	0.601	0.038	0.018	0.577	0.640	
Slovenia	0.730	0.672	0.058	0.028	0.629	0.736	
Spain	0.836	0.730	0.106	0.070	0.647	0.903	
Sweden	0.972	0.817	0.155	0.110	0.681	1.084	
United Kingdom	1.000	0.735	0.265	0.149	0.494	1.031	
Country	**Efficiency scores**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2014**
Austria	0.527	0.514	0.013	0.007	0.504	0.528	
Belgium	0.514	0.502	0.011	0.005	0.493	0.511	
Bulgaria	0.545	0.525	0.020	0.013	0.509	0.551	
Cyprus	1.000	-13.013	14.013	112.138	-27.026	-3.689	
Czech Republic	0.583	0.472	0.110	0.066	0.374	0.589	
Denmark	0.551	0.498	0.053	0.029	0.452	0.554	
Estonia	1.000	-4.939	5.939	16.289	-10.878	41.250	
Finland	1.000	-4.485	5.485	13.213	-9.971	45.590	

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

UNIVERSITY OF THESSALY

Department Of Economics

France	1.000	0.815	0.185	0.126	0.645	1.082
Germany	1.000	0.880	0.119	0.073	0.777	1.043
Greece	1.000	0.849	0.150	0.097	0.714	1.059
Hungary	0.768	0.711	0.056	0.026	0.675	0.766
Ireland	1.000	0.847	0.152	0.084	0.714	1.005
Italy	0.902	0.792	0.109	0.080	0.702	0.947
Latvia	0.554	0.541	0.013	0.007	0.532	0.555
Lithuania	0.689	0.643	0.046	0.022	0.611	0.691
Luxembourg	1.000	0.765	0.235	0.208	0.550	1.202
Malta	0.756	0.704	0.052	0.025	0.666	0.753
Netherlands	0.854	0.780	0.074	0.042	0.730	0.864
Norway	1.000	0.724	0.276	0.190	0.480	1.078
Poland	0.744	0.669	0.075	0.047	0.609	0.784
Portugal	0.877	0.791	0.086	0.053	0.724	0.918
Romania	0.597	0.574	0.023	0.011	0.558	0.598
Slovakia	0.655	0.615	0.041	0.018	0.585	0.655
Slovenia	0.806	0.752	0.055	0.026	0.719	0.807
Spain	0.964	0.870	0.094	0.074	0.792	1.024
Sweden	0.999	0.875	0.124	0.090	0.770	1.109
United Kingdom	1.000	0.827	0.172	0.113	0.674	1.052

France	0.506	0.500	0.006	0.004	0.495	0.507
Germany	0.505	0.498	0.007	0.004	0.492	0.505
Greece	0.526	0.515	0.011	0.006	0.506	0.527
Hungary	1.000	0.057	0.943	0.617	-0.845	1.147
Ireland	0.588	0.540	0.048	0.028	0.502	0.597
Italy	0.504	0.499	0.005	0.003	0.495	0.504
Latvia	0.757	0.470	0.286	0.269	0.211	0.972
Lithuania	0.625	0.548	0.077	0.058	0.483	0.656
Luxembourg	1.000	-4.073	5.073	9.584	-9.145	29.940
Malta	1.000	-21.941	22.941	132.349	-44.883	17.668
Netherlands	0.510	0.500	0.009	0.004	0.493	0.508
Norway	1.000	-5.643	6.643	26.806	-12.286	24.464
Poland	0.520	0.501	0.019	0.010	0.485	0.521
Portugal	0.522	0.513	0.009	0.005	0.507	0.523
Romania	0.535	0.513	0.023	0.011	0.494	0.535
Slovakia	0.563	0.538	0.024	0.015	0.521	0.577
Slovenia	0.766	0.609	0.156	0.149	0.488	1.029
Spain	0.507	0.502	0.005	0.003	0.498	0.507
Sweden	1.000	0.344	0.656	0.424	-0.276	1.006
United Kingdom	0.505	0.499	0.006	0.003	0.494	0.505

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Framework M3

Country	Efficiency scores	Bias corrected	bias	std	lower	upper	2008	Country	Efficiency scores	Bias corrected	bias	std	lower	upper	2010
Austria	0.931	0.867	0.064	0.042	0.815	0.962		**Austria**	0.944	0.876	0.068	0.048	0.821	1.006	
Belgium	0.898	0.839	0.060	0.035	0.788	0.912		**Belgium**	0.875	0.813	0.062	0.040	0.761	0.900	
Bulgaria	0.614	0.570	0.044	0.017	0.539	0.606		**Bulgaria**	0.642	0.598	0.044	0.019	0.569	0.640	
Cyprus	1.000	0.679	0.321	0.912	0.368	2.117		**Cyprus**	1.000	0.739	0.261	0.524	0.488	2.344	
Czech Republic	0.592	0.548	0.043	0.023	0.512	0.585		**Czech Republic**	0.572	0.542	0.030	0.018	0.519	0.587	
Denmark	0.948	0.886	0.061	0.039	0.834	0.979		**Denmark**	0.943	0.878	0.065	0.044	0.821	0.980	
Estonia	1.000	0.628	0.372	0.818	0.262	3.033		**Estonia**	1.000	0.443	0.557	2.085	-0.106	2.569	
Finland	1.000	0.621	0.379	1.370	0.254	2.717		**Finland**	1.000	0.724	0.276	0.597	0.461	2.393	
France	1.000	0.845	0.155	0.192	0.702	1.324		**France**	1.000	0.838	0.162	0.195	0.690	1.343	
Germany	1.000	0.726	0.274	0.319	0.463	1.571		**Germany**	1.000	0.726	0.274	0.306	0.462	1.451	
Greece	1.000	0.787	0.213	0.440	0.583	2.305		**Greece**	1.000	0.782	0.218	0.460	0.572	2.172	
Hungary	0.832	0.794	0.038	0.019	0.766	0.840		**Hungary**	0.790	0.747	0.043	0.023	0.716	0.804	
Ireland	1.000	0.910	0.090	0.090	0.833	1.218		**Ireland**	1.000	0.855	0.145	0.155	0.724	1.223	
Italy	0.957	0.888	0.069	0.059	0.832	1.023		**Italy**	0.961	0.894	0.067	0.054	0.839	1.035	
Latvia	1.000	0.797	0.203	0.332	0.608	2.017		**Latvia**	1.000	0.794	0.206	0.357	0.602	1.835	
Lithuania	1.000	0.875	0.125	0.113	0.762	1.185		**Lithuania**	1.000	0.884	0.116	0.100	0.779	1.137	
Luxembourg	1.000	-0.623	1.623	9.886	-2.235	8.182		**Luxembourg**	1.000	0.542	0.458	1.006	0.095	3.716	
Malta	1.000	0.656	0.344	0.638	0.321	2.420		**Malta**	1.000	0.638	0.362	0.651	0.286	2.717	

Netherlands	1.000	0.726	0.274	0.316	0.467	1.468	
Norway	1.000	0.551	0.449	0.795	0.114	2.740	
Poland	0.743	0.694	0.049	0.028	0.659	0.752	
Portugal	0.858	0.814	0.045	0.026	0.780	0.874	
Romania	0.501	0.478	0.023	0.019	0.455	0.511	
Slovakia	0.680	0.636	0.044	0.016	0.607	0.670	
Slovenia	0.805	0.749	0.056	0.028	0.712	0.819	
Spain	0.928	0.842	0.086	0.099	0.766	1.139	
Sweden	0.978	0.900	0.078	0.077	0.834	1.149	
United Kingdom	1.000	0.852	0.148	0.150	0.716	1.202	
Country	**Efficiency scores**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2012**
Austria	0.985	0.916	0.069	0.056	0.857	1.081	
Belgium	0.908	0.853	0.055	0.033	0.807	0.921	
Bulgaria	0.591	0.565	0.026	0.017	0.546	0.611	
Cyprus	1.000	0.735	0.266	0.539	0.480	2.394	
Czech Republic	0.587	0.557	0.029	0.019	0.536	0.607	
Denmark	0.959	0.899	0.060	0.043	0.848	1.025	
Estonia	1.000	0.511	0.489	1.552	0.031	2.830	
Finland	1.000	0.734	0.266	0.552	0.478	2.276	

Netherlands	1.000	0.747	0.253	0.272	0.513	1.349	
Norway	1.000	0.548	0.452	0.827	0.109	2.484	
Poland	0.776	0.727	0.049	0.028	0.692	0.799	
Portugal	0.795	0.747	0.048	0.031	0.714	0.816	
Romania	0.546	0.521	0.025	0.021	0.501	0.572	
Slovakia	0.627	0.583	0.044	0.032	0.546	0.662	
Slovenia	0.878	0.821	0.056	0.034	0.780	0.921	
Spain	0.907	0.818	0.090	0.106	0.740	1.133	
Sweden	0.986	0.907	0.079	0.079	0.840	1.152	
United Kingdom	1.000	0.842	0.158	0.169	0.696	1.291	
Country	**Efficiency scores**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2014**
Austria	0.565	0.470	0.095	0.059	0.385	0.581	
Belgium	0.510	0.492	0.018	0.012	0.476	0.511	
Bulgaria	0.584	0.518	0.066	0.036	0.461	0.589	
Cyprus	1.000	-2.532	3.532	14.966	-6.064	9.644	
Czech Republic	0.556	0.471	0.086	0.062	0.390	0.578	
Denmark	0.598	0.465	0.133	0.101	0.343	0.635	
Estonia	1.000	-2.921	3.921	7.314	-6.841	23.687	
Finland	1.000	-2.141	3.141	6.856	-5.282	20.548	

France	1.000	0.847	0.153	0.198	0.704	1.324
Germany	1.000	0.739	0.261	0.305	0.488	1.428
Greece	1.000	0.796	0.204	0.407	0.599	2.006
Hungary	0.746	0.705	0.041	0.021	0.680	0.750
Ireland	1.000	0.857	0.143	0.173	0.726	1.300
Italy	0.955	0.890	0.066	0.063	0.834	1.053
Latvia	1.000	0.786	0.214	0.414	0.585	2.312
Lithuania	1.000	0.870	0.129	0.140	0.751	1.157
Luxembourg	1.000	0.571	0.429	0.915	0.153	3.355
Malta	1.000	0.676	0.324	0.554	0.359	2.097
Netherlands	1.000	0.879	0.121	0.123	0.773	1.236
Norway	1.000	0.527	0.473	0.806	0.067	2.774
Poland	0.766	0.724	0.041	0.023	0.698	0.792
Portugal	0.855	0.809	0.046	0.042	0.773	0.878
Romania	0.552	0.532	0.019	0.018	0.516	0.582
Slovakia	0.661	0.619	0.042	0.027	0.587	0.698
Slovenia	0.939	0.884	0.055	0.044	0.844	0.964
Spain	1.000	0.920	0.080	0.089	0.850	1.161
Sweden	1.000	0.910	0.090	0.087	0.831	1.216
United Kingdom	1.000	0.863	0.137	0.148	0.737	1.219

France	0.507	0.496	0.011	0.008	0.486	0.507
Germany	0.522	0.486	0.036	0.027	0.451	0.531
Greece	1.000	-1.866	2.866	6.563	-4.733	19.486
Hungary	1.000	0.159	0.841	0.639	-0.648	1.223
Ireland	0.554	0.491	0.062	0.034	0.439	0.561
Italy	0.505	0.497	0.009	0.006	0.489	0.506
Latvia	1.000	-1.829	2.829	5.112	-4.659	13.183
Lithuania	0.972	0.423	0.548	0.727	-0.098	2.300
Luxembourg	1.000	-6.612	7.612	36.330	-14.225	11.209
Malta	1.000	-4.470	5.470	22.708	-9.941	29.307
Netherlands	0.528	0.483	0.045	0.033	0.440	0.541
Norway	1.000	-3.659	4.659	13.338	-8.317	28.346
Poland	0.510	0.494	0.015	0.011	0.480	0.511
Portugal	0.509	0.504	0.005	0.002	0.500	0.509
Romania	0.516	0.502	0.014	0.008	0.489	0.516
Slovakia	0.559	0.531	0.028	0.020	0.509	0.578
Slovenia	0.845	0.565	0.280	0.352	0.328	1.491
Spain	0.511	0.493	0.019	0.013	0.475	0.515
Sweden	1.000	0.500	0.500	0.385	0.035	1.206
United Kingdom	0.506	0.496	0.010	0.007	0.487	0.507

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Table 1.7: Bias corrected efficiency scores of the 22 countries for modelling framework M1

DMU	VRS	Bias corrected	bias	std	lower	upper	2005
Austria	0.820	0.773	0.047	0.023	0.742	0.817	
Belgium	0.855	0.798	0.057	0.026	0.760	0.854	
Bulgaria	0.730	0.702	0.029	0.017	0.684	0.736	
Croatia	0.744	0.713	0.030	0.017	0.695	0.748	
Czech Rep	0.672	0.629	0.043	0.018	0.601	0.667	
Denmark	0.892	0.849	0.043	0.022	0.819	0.897	
Estonia	0.574	0.551	0.023	0.013	0.537	0.579	
Finland	0.823	0.783	0.040	0.020	0.757	0.827	
France	0.910	0.754	0.156	0.099	0.626	0.962	
Germany	1.000	0.738	0.262	0.149	0.512	1.046	
Greece	0.907	0.860	0.047	0.023	0.828	0.908	
Hungary	0.795	0.760	0.035	0.019	0.737	0.796	
Ireland	0.634	0.598	0.036	0.016	0.575	0.631	
Italy	0.901	0.777	0.124	0.078	0.677	0.953	
Netherlands	0.922	0.845	0.077	0.037	0.789	0.916	
Poland	1.000	0.941	0.059	0.028	0.901	0.995	
Portugal	0.818	0.778	0.040	0.020	0.752	0.820	
Romania	0.778	0.744	0.034	0.018	0.722	0.778	
Slovakia	0.691	0.662	0.029	0.016	0.643	0.692	
Slovenia	0.709	0.681	0.028	0.016	0.663	0.714	
Spain	0.694	0.624	0.070	0.041	0.567	0.709	
Sweden	0.855	0.800	0.055	0.025	0.763	0.852	

DMU	VRS	Bias corrected	bias	std	lower	upper	2010
Austria	0.843	0.811	0.032	0.014	0.793	0.847	
Belgium	0.856	0.823	0.034	0.019	0.802	0.869	
Bulgaria	0.656	0.611	0.044	0.026	0.576	0.658	
Croatia	0.725	0.683	0.042	0.022	0.652	0.728	
Czech Rep	0.698	0.675	0.024	0.013	0.660	0.709	
Denmark	0.956	0.913	0.042	0.020	0.886	0.958	
Estonia	0.633	0.582	0.050	0.033	0.539	0.651	
Finland	0.817	0.789	0.028	0.012	0.774	0.822	
France	0.937	0.823	0.114	0.096	0.725	1.081	
Germany	1.000	0.826	0.174	0.125	0.673	1.134	
Greece	0.993	0.949	0.045	0.020	0.920	0.992	
Hungary	0.824	0.786	0.039	0.018	0.762	0.831	
Ireland	0.952	0.903	0.050	0.025	0.867	0.957	

Italy	0.971	0.887	0.084	0.070	0.817	1.056
Netherlands	0.951	0.903	0.048	0.030	0.870	0.978
Poland	0.929	0.891	0.038	0.023	0.867	0.954
Portugal	0.849	0.813	0.036	0.016	0.793	0.851
Romania	0.711	0.689	0.022	0.010	0.677	0.719
Slovakia	0.764	0.733	0.031	0.014	0.716	0.771
Slovenia	1.000	0.812	0.188	0.129	0.639	1.039
Spain	0.839	0.780	0.060	0.049	0.733	0.896
Sweden	0.843	0.812	0.031	0.019	0.793	0.860

DMU	VRS	Bias corrected	bias	std	lower	upper	2015
Austria	0.713	0.656	0.057	0.031	0.618	0.736	
Belgium	0.716	0.647	0.069	0.043	0.596	0.755	
Bulgaria	0.615	0.545	0.070	0.038	0.488	0.639	
Croatia	0.634	0.549	0.085	0.047	0.476	0.664	
Czech Rep	0.625	0.580	0.045	0.028	0.548	0.653	
Denmark	0.819	0.758	0.061	0.033	0.718	0.844	
Estonia	0.557	0.510	0.047	0.030	0.470	0.590	
Finland	0.739	0.678	0.061	0.027	0.638	0.741	
France	0.941	0.711	0.229	0.171	0.514	1.092	
Germany	1.000	0.668	0.332	0.207	0.373	1.080	
Greece	1.000	0.735	0.265	0.121	0.495	0.922	
Hungary	0.679	0.628	0.051	0.023	0.594	0.684	
Ireland	0.748	0.680	0.068	0.030	0.633	0.742	
Italy	1.000	0.768	0.232	0.146	0.576	1.069	
Netherlands	0.846	0.752	0.094	0.057	0.681	0.877	
Poland	0.827	0.744	0.083	0.055	0.680	0.880	
Portugal	0.871	0.752	0.118	0.056	0.658	0.849	
Romania	0.665	0.615	0.050	0.030	0.581	0.697	
Slovakia	0.633	0.590	0.042	0.019	0.563	0.635	
Slovenia	0.617	0.511	0.106	0.058	0.414	0.650	
Spain	0.853	0.709	0.144	0.104	0.585	0.932	
Sweden	0.707	0.639	0.068	0.043	0.588	0.744	

Table 1.8: Bias corrected efficiency scores of the 22 countries for modelling framework M2

DMU	VRS	Bias corrected	bias	std	lower	upper	2005
Austria	0.823	0.773	0.050	0.025	0.738	0.829	
Belgium	0.855	0.805	0.050	0.025	0.772	0.857	
Bulgaria	0.730	0.707	0.023	0.010	0.695	0.733	
Croatia	0.744	0.718	0.026	0.012	0.704	0.745	
Czech Rep	0.672	0.631	0.040	0.019	0.604	0.672	
Denmark	0.892	0.851	0.041	0.018	0.825	0.890	
Estonia	0.574	0.555	0.019	0.009	0.545	0.576	
Finland	0.858	0.770	0.088	0.050	0.702	0.870	
France	1.000	0.713	0.287	0.193	0.449	1.117	
Germany	1.000	0.749	0.251	0.163	0.520	1.079	
Greece	0.910	0.863	0.047	0.023	0.829	0.911	
Hungary	0.795	0.765	0.030	0.013	0.748	0.797	
Ireland	0.637	0.589	0.048	0.025	0.553	0.646	
Italy	0.901	0.779	0.122	0.088	0.673	0.974	
Netherlands	0.922	0.852	0.070	0.037	0.799	0.920	
Poland	1.000	0.942	0.058	0.027	0.904	1.002	
Portugal	0.818	0.781	0.037	0.017	0.759	0.819	
Romania	0.778	0.748	0.029	0.013	0.731	0.780	
Slovakia	0.691	0.666	0.025	0.011	0.651	0.695	
Slovenia	0.709	0.686	0.023	0.011	0.673	0.712	
Spain	0.726	0.610	0.116	0.078	0.514	0.773	
Sweden	0.952	0.828	0.124	0.089	0.722	1.040	

DMU	VRS	Bias corrected	bias	std	lower	upper	2010
Austria	0.846	0.805	0.041	0.020	0.775	0.852	
Belgium	0.856	0.823	0.033	0.019	0.802	0.867	
Bulgaria	0.656	0.615	0.041	0.024	0.580	0.665	
Croatia	0.725	0.686	0.039	0.020	0.656	0.731	
Czech Rep	0.698	0.672	0.026	0.015	0.654	0.705	
Denmark	0.956	0.910	0.045	0.021	0.877	0.956	
Estonia	0.633	0.587	0.046	0.031	0.546	0.654	
Finland	0.901	0.848	0.053	0.032	0.807	0.922	
France	1.000	0.802	0.198	0.180	0.621	1.226	
Germany	1.000	0.837	0.163	0.134	0.688	1.165	
Greece	1.000	0.947	0.053	0.021	0.914	0.997	

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Hungary	0.824	0.787	0.038	0.017	0.761	0.820
Ireland	0.994	0.949	0.046	0.022	0.914	0.996
Italy	0.971	0.895	0.077	0.070	0.829	1.080
Netherlands	0.951	0.905	0.046	0.027	0.872	0.969
Poland	0.929	0.884	0.045	0.030	0.851	0.958
Portugal	0.849	0.810	0.038	0.017	0.784	0.844
Romania	0.711	0.685	0.026	0.013	0.668	0.717
Slovakia	0.764	0.734	0.030	0.014	0.715	0.761
Slovenia	1.000	0.830	0.170	0.126	0.669	1.067
Spain	0.883	0.801	0.082	0.060	0.736	0.942
Sweden	0.965	0.878	0.086	0.073	0.806	1.064

DMU	VRS	Bias corrected	bias	std	lower	upper	2015
Austria	0.713	0.642	0.071	0.036	0.596	0.731	
Belgium	0.716	0.651	0.065	0.038	0.607	0.741	
Bulgaria	0.615	0.560	0.055	0.031	0.516	0.633	
Croatia	0.634	0.567	0.066	0.038	0.511	0.658	
Czech Rep	0.625	0.581	0.044	0.023	0.552	0.639	
Denmark	0.819	0.760	0.059	0.028	0.723	0.829	
Estonia	0.557	0.519	0.038	0.026	0.487	0.587	
Finland	0.953	0.869	0.084	0.069	0.802	1.045	
France	1.000	0.675	0.325	0.256	0.377	1.225	
Germany	1.000	0.714	0.286	0.222	0.450	1.153	
Greece	1.000	0.767	0.233	0.129	0.556	0.972	
Hungary	0.679	0.634	0.045	0.019	0.606	0.680	
Ireland	0.770	0.684	0.086	0.045	0.620	0.796	
Italy	1.000	0.781	0.219	0.148	0.598	1.123	
Netherlands	0.846	0.758	0.089	0.052	0.692	0.866	
Poland	0.827	0.737	0.090	0.054	0.670	0.856	
Portugal	0.871	0.768	0.103	0.056	0.687	0.881	
Romania	0.665	0.613	0.052	0.027	0.577	0.674	
Slovakia	0.633	0.595	0.037	0.016	0.572	0.634	
Slovenia	0.617	0.535	0.083	0.048	0.459	0.653	
Spain	0.974	0.851	0.123	0.101	0.748	1.128	
Sweden	0.912	0.750	0.163	0.155	0.609	1.113	

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Table 1.9: Efficiency scores of M1 and M2 frameworks for the EU countries for 2008, 2010, 2012, 2014 and 2016

	M1					M2				
Country	**2008**	**2010**	**2012**	**2014**	**2016**	**2008**	**2010**	**2012**	**2014**	**2016**
Austria	0.528	0.523	0.529	0.531	0.527	0.528	0.523	0.529	0.531	0.527
Belgium	0.507	0.507	0.508	0.507	0.506	0.507	0.507	0.508	0.507	0.506
Bulgaria	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501
Croatia	0.515	0.516	0.514	0.513	0.513	0.515	0.516	0.514	0.513	0.513
Cyprus	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502
Czechia	0.534	0.532	0.529	0.528	0.530	0.534	0.532	0.529	0.528	0.530
Denmark	0.567	0.579	0.588	0.604	0.572	0.567	0.579	0.588	0.604	0.572
Estonia	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501	0.501
Finland	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503
France	0.510	0.510	0.510	0.512	0.510	0.510	0.510	0.510	0.512	0.510
Germany	0.504	0.504	0.503	0.503	0.503	0.504	0.504	0.503	0.503	0.503
Greece	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502
Hungary	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ireland	0.504	0.506	0.506	0.506	0.507	0.504	0.506	0.506	0.506	0.507
Italy	0.508	0.508	0.507	0.507	0.506	0.508	0.508	0.507	0.507	0.506
Latvia	0.511	0.506	0.507	0.507	0.503	0.511	0.506	0.507	0.507	0.503
Lithuania	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502
Luxembourg	1.000	1.000	1.000	1.000	0.824	1.000	1.000	1.000	1.000	0.824
Malta	0.502	0.502	0.502	0.502	0.505	0.502	0.502	0.502	0.502	0.505
Netherlands	0.508	0.508	0.507	0.506	0.505	0.508	0.508	0.507	0.506	0.505
Poland	0.504	0.504	0.504	0.503	0.504	0.504	0.504	0.504	0.503	0.504
Portugal	0.503	0.503	0.503	0.502	0.502	0.503	0.503	0.503	0.502	0.502

Romania	0.505	0.506	0.505	0.505	0.506	0.505	0.506	0.505	0.505	0.506
Slovakia	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502
Slovenia	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502
Spain	0.503	0.504	0.503	0.503	0.503	0.503	0.504	0.503	0.503	0.503
Sweden	0.649	0.596	0.621	0.665	0.606	0.650	0.608	0.622	0.665	0.606
United Kingdom	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503	0.503

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Table 1.10: Average scores per country and per modelling frameworks

Country	M1	M2
Austria	0.528	0.528
Belgium	0.507	0.507
Bulgaria	0.501	0.501
Croatia	0.514	0.514
Cyprus	0.502	0.502
Czechia	0.530	0.530
Denmark	0.582	0.582
Estonia	0.501	0.501
Finland	0.503	0.503
France	0.510	0.510
Germany	0.503	0.503
Greece	0.502	0.502
Hungary	1.000	1.000
Ireland	0.506	0.506
Italy	0.507	0.507
Latvia	0.507	0.507
Lithuania	0.502	0.502
Luxembourg	0.965	0.965
Malta	0.503	0.503
Netherlands	0.507	0.507
Poland	0.504	0.504
Portugal	0.503	0.503
Romania	0.506	0.506
Slovakia	0.502	0.502
Slovenia	0.502	0.502
Spain	0.503	0.503
Sweden	0.628	0.630
United Kingdom	0.503	0.503

Table 1.11: Bias corrected efficiency scores of countries' by modelling framework

Framework M1

Country	Score original	Bias corrected	bias	std	lower	upper	2008
Austria	0.528	0.461	0.067	0.027	0.402	0.498	
Belgium	0.507	0.490	0.017	0.006	0.475	0.499	
Bulgaria	0.501	0.498	0.004	0.001	0.494	0.499	
Croatia	0.515	0.475	0.040	0.012	0.439	0.493	
Cyprus	0.502	0.496	0.006	0.002	0.491	0.499	
Czechia	0.534	0.446	0.087	0.026	0.367	0.484	

Denmark	0.567	0.396	0.171	0.052	0.241	0.474
Estonia	0.501	0.499	0.002	0.001	0.496	0.500
Finland	0.503	0.495	0.009	0.003	0.486	0.499
France	0.510	0.486	0.023	0.008	0.465	0.498
Germany	0.504	0.494	0.010	0.003	0.485	0.499
Greece	0.502	0.496	0.006	0.002	0.491	0.499
Hungary	1.000	-0.304	1.304	0.385	-1.490	0.248
Ireland	0.504	0.494	0.010	0.003	0.484	0.498
Italy	0.508	0.487	0.021	0.006	0.468	0.496
Latvia	0.511	0.485	0.025	0.010	0.463	0.499
Lithuania	0.502	0.496	0.006	0.002	0.491	0.499
Luxembourg	1.000	-0.287	1.287	0.331	-1.037	0.255
Malta	0.502	0.497	0.005	0.002	0.492	0.499
Netherlands	0.508	0.489	0.019	0.007	0.472	0.498
Poland	0.504	0.494	0.010	0.003	0.485	0.498
Portugal	0.503	0.495	0.008	0.002	0.488	0.499
Romania	0.505	0.492	0.013	0.004	0.480	0.498
Slovakia	0.502	0.496	0.006	0.002	0.491	0.499
Slovenia	0.502	0.497	0.005	0.002	0.492	0.499
Spain	0.503	0.495	0.009	0.003	0.487	0.499
Sweden	0.649	0.294	0.355	0.142	-0.025	0.490
United Kingdom	0.503	0.495	0.007	0.002	0.489	0.499

Country	Score original	Bias corrected	bias	std	lower	upper	2010
Austria	0.523	0.466	0.057	0.020	0.415	0.495	
Belgium	0.507	0.489	0.018	0.006	0.472	0.498	
Bulgaria	0.501	0.498	0.004	0.001	0.494	0.499	
Croatia	0.516	0.475	0.042	0.013	0.437	0.494	
Cyprus	0.502	0.496	0.006	0.002	0.491	0.499	
Czechia	0.532	0.449	0.082	0.024	0.375	0.484	
Denmark	0.579	0.376	0.203	0.061	0.192	0.466	
Estonia	0.501	0.499	0.002	0.001	0.497	0.500	
Finland	0.503	0.496	0.007	0.002	0.489	0.499	
France	0.510	0.485	0.026	0.009	0.461	0.497	
Germany	0.504	0.494	0.009	0.003	0.486	0.499	
Greece	0.502	0.497	0.006	0.002	0.492	0.499	
Hungary	1.000	-0.313	1.313	0.376	-1.508	0.229	
Ireland	0.506	0.491	0.015	0.005	0.478	0.498	
Italy	0.508	0.486	0.022	0.006	0.467	0.496	
Latvia	0.506	0.492	0.014	0.005	0.479	0.499	

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Lithuania	0.502	0.497	0.005	0.001	0.492	0.499
Luxembourg	1.000	-0.302	1.302	0.338	-1.195	0.226
Malta	0.502	0.496	0.006	0.002	0.491	0.499
Netherlands	0.508	0.488	0.020	0.007	0.470	0.498
Poland	0.504	0.494	0.010	0.003	0.485	0.498
Portugal	0.503	0.495	0.008	0.003	0.487	0.499
Romania	0.506	0.491	0.014	0.004	0.478	0.498
Slovakia	0.502	0.497	0.006	0.002	0.491	0.499
Slovenia	0.502	0.497	0.005	0.002	0.492	0.499
Spain	0.504	0.493	0.011	0.003	0.483	0.499
Sweden	0.596	0.359	0.237	0.084	0.144	0.479
United Kingdom	0.503	0.496	0.007	0.002	0.489	0.499

Country	**Score original**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2012**
Austria	0.529	0.459	0.070	0.027	0.397	0.497	
Belgium	0.508	0.488	0.020	0.007	0.469	0.498	
Bulgaria	0.501	0.498	0.003	0.001	0.495	0.499	
Croatia	0.514	0.478	0.037	0.011	0.444	0.494	
Cyprus	0.502	0.497	0.006	0.002	0.491	0.499	
Czechia	0.529	0.454	0.076	0.022	0.385	0.486	
Denmark	0.588	0.375	0.213	0.078	0.184	0.488	
Estonia	0.501	0.499	0.002	0.001	0.497	0.500	
Finland	0.503	0.495	0.008	0.002	0.488	0.499	
France	0.510	0.485	0.025	0.008	0.462	0.497	
Germany	0.503	0.495	0.008	0.003	0.488	0.499	
Greece	0.502	0.497	0.004	0.001	0.494	0.499	
Hungary	1.000	-0.306	1.306	0.383	-1.494	0.244	
Ireland	0.506	0.492	0.014	0.005	0.479	0.498	
Italy	0.507	0.489	0.018	0.006	0.472	0.498	
Latvia	0.507	0.491	0.016	0.006	0.477	0.499	
Lithuania	0.502	0.497	0.005	0.002	0.492	0.499	
Luxembourg	1.000	-0.279	1.279	0.347	-1.133	0.273	
Malta	0.502	0.497	0.005	0.001	0.492	0.499	
Netherlands	0.507	0.489	0.018	0.006	0.472	0.498	
Poland	0.504	0.494	0.010	0.003	0.485	0.498	
Portugal	0.503	0.496	0.007	0.002	0.489	0.499	
Romania	0.505	0.492	0.013	0.004	0.480	0.498	
Slovakia	0.502	0.497	0.006	0.002	0.491	0.499	
Slovenia	0.502	0.497	0.004	0.001	0.493	0.499	
Spain	0.503	0.495	0.008	0.002	0.488	0.499	

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Sweden	0.621	0.328	0.293	0.112	0.064	0.485
United Kingdom	0.503	0.496	0.007	0.002	0.490	0.499

Country	**Score original**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2014**
Austria	0.531	0.460	0.071	0.030	0.396	0.499	
Belgium	0.507	0.489	0.018	0.006	0.472	0.497	
Bulgaria	0.501	0.498	0.003	0.001	0.495	0.499	
Croatia	0.513	0.480	0.033	0.010	0.450	0.494	
Cyprus	0.502	0.497	0.005	0.001	0.493	0.499	
Czechia	0.528	0.456	0.072	0.022	0.391	0.487	
Denmark	0.604	0.358	0.246	0.097	0.138	0.492	
Estonia	0.501	0.499	0.002	0.001	0.497	0.500	
Finland	0.503	0.495	0.008	0.002	0.489	0.499	
France	0.512	0.482	0.030	0.009	0.454	0.496	
Germany	0.503	0.496	0.007	0.002	0.490	0.499	
Greece	0.502	0.498	0.004	0.001	0.494	0.499	
Hungary	1.000	-0.297	1.297	0.396	-1.475	0.270	
Ireland	0.506	0.491	0.016	0.005	0.476	0.498	
Italy	0.507	0.489	0.019	0.006	0.471	0.497	
Latvia	0.507	0.491	0.015	0.007	0.477	0.500	
Lithuania	0.502	0.496	0.006	0.002	0.491	0.499	
Luxembourg	1.000	-0.117	1.117	0.458	-1.106	0.465	
Malta	0.502	0.497	0.006	0.002	0.491	0.499	
Netherlands	0.506	0.491	0.016	0.005	0.476	0.498	
Poland	0.503	0.495	0.009	0.003	0.486	0.498	
Portugal	0.502	0.496	0.006	0.002	0.490	0.499	
Romania	0.505	0.492	0.014	0.004	0.479	0.498	
Slovakia	0.502	0.496	0.006	0.002	0.491	0.499	
Slovenia	0.502	0.497	0.005	0.001	0.493	0.499	
Spain	0.503	0.496	0.007	0.002	0.489	0.499	
Sweden	0.665	0.281	0.384	0.162	-0.064	0.496	
United Kingdom	0.503	0.496	0.007	0.002	0.489	0.499	

Country	**Score original**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2016**
Austria	0.527	0.456	0.071	0.022	0.402	0.488	
Belgium	0.506	0.487	0.018	0.004	0.478	0.496	
Bulgaria	0.501	0.498	0.003	0.001	0.495	0.499	
Croatia	0.513	0.480	0.033	0.009	0.450	0.492	
Cyprus	0.502	0.497	0.005	0.001	0.493	0.499	

Czechia	0.530	0.458	0.072	0.021	0.382	0.480
Denmark	0.572	0.326	0.246	0.056	0.236	0.469
Estonia	0.501	0.499	0.002	0.001	0.497	0.500
Finland	0.503	0.496	0.008	0.002	0.488	0.498
France	0.510	0.479	0.030	0.007	0.462	0.493
Germany	0.503	0.496	0.007	0.002	0.490	0.498
Greece	0.502	0.498	0.004	0.001	0.494	0.499
Hungary	1.000	-0.297	1.297	0.350	-1.482	0.148
Ireland	0.507	0.492	0.016	0.005	0.473	0.496
Italy	0.506	0.487	0.019	0.004	0.476	0.496
Latvia	0.503	0.488	0.015	0.003	0.488	0.499
Lithuania	0.502	0.496	0.006	0.002	0.492	0.499
Luxembourg	0.824	-0.293	1.117	0.258	-0.607	0.376
Malta	0.505	0.499	0.006	0.003	0.482	0.497
Netherlands	0.505	0.489	0.016	0.003	0.481	0.497
Poland	0.504	0.495	0.009	0.003	0.486	0.498
Portugal	0.502	0.496	0.006	0.002	0.490	0.499
Romania	0.506	0.493	0.014	0.005	0.475	0.496
Slovakia	0.502	0.497	0.006	0.002	0.491	0.498
Slovenia	0.502	0.498	0.005	0.002	0.491	0.499
Spain	0.503	0.496	0.007	0.002	0.489	0.498
Sweden	0.606	0.222	0.384	0.086	0.110	0.457
United Kingdom	0.503	0.496	0.007	0.002	0.488	0.498

Framework M2

Country	Score original	Bias corrected	bias	std	lower	upper	2008
Austria	0.528	0.461	0.068	0.027	0.400	0.498	
Belgium	0.507	0.490	0.017	0.006	0.475	0.499	
Bulgaria	0.501	0.498	0.004	0.001	0.494	0.499	
Croatia	0.515	0.475	0.040	0.012	0.439	0.493	
Cyprus	0.502	0.496	0.006	0.002	0.491	0.499	
Czechia	0.534	0.446	0.087	0.026	0.367	0.484	
Denmark	0.567	0.396	0.171	0.052	0.241	0.474	
Estonia	0.501	0.499	0.002	0.001	0.496	0.500	
Finland	0.503	0.495	0.009	0.003	0.486	0.499	
France	0.510	0.486	0.023	0.008	0.465	0.498	
Germany	0.504	0.494	0.010	0.003	0.485	0.499	
Greece	0.502	0.496	0.006	0.002	0.491	0.499	
Hungary	1.000	-0.304	1.304	0.385	-1.490	0.249	
Ireland	0.504	0.494	0.010	0.003	0.484	0.498	

Italy	0.508	0.487	0.021	0.006	0.468	0.496
Latvia	0.511	0.485	0.025	0.010	0.463	0.499
Lithuania	0.502	0.496	0.006	0.002	0.491	0.499
Luxembourg	1.000	-0.287	1.287	0.330	-1.037	0.255
Malta	0.502	0.497	0.005	0.002	0.492	0.499
Netherlands	0.508	0.489	0.019	0.007	0.472	0.498
Poland	0.504	0.494	0.010	0.003	0.485	0.498
Portugal	0.503	0.495	0.008	0.002	0.488	0.499
Romania	0.505	0.492	0.013	0.004	0.480	0.498
Slovakia	0.502	0.496	0.006	0.002	0.491	0.499
Slovenia	0.502	0.497	0.005	0.002	0.492	0.499
Spain	0.503	0.495	0.009	0.003	0.487	0.499
Sweden	0.650	0.218	0.431	0.173	-0.178	0.387
United Kingdom	0.503	0.495	0.007	0.002	0.489	0.499

Country	**Score original**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2010**
Austria	0.523	0.466	0.058	0.020	0.414	0.495	
Belgium	0.507	0.489	0.019	0.006	0.472	0.498	
Bulgaria	0.501	0.498	0.004	0.001	0.494	0.499	
Croatia	0.516	0.475	0.042	0.013	0.436	0.494	
Cyprus	0.502	0.496	0.006	0.002	0.491	0.499	
Czechia	0.532	0.449	0.082	0.024	0.375	0.484	
Denmark	0.579	0.376	0.203	0.062	0.192	0.467	
Estonia	0.501	0.499	0.002	0.001	0.497	0.500	
Finland	0.503	0.496	0.007	0.002	0.489	0.499	
France	0.510	0.485	0.026	0.008	0.461	0.497	
Germany	0.504	0.494	0.009	0.003	0.486	0.499	
Greece	0.502	0.497	0.006	0.002	0.492	0.499	
Hungary	1.000	-0.311	1.311	0.378	-1.504	0.233	
Ireland	0.506	0.491	0.015	0.005	0.478	0.498	
Italy	0.508	0.487	0.022	0.006	0.467	0.496	
Latvia	0.506	0.491	0.014	0.005	0.479	0.499	
Lithuania	0.502	0.497	0.005	0.001	0.492	0.499	
Luxembourg	1.000	-0.306	1.306	0.337	-1.203	0.219	
Malta	0.502	0.496	0.006	0.002	0.491	0.499	
Netherlands	0.508	0.488	0.020	0.007	0.470	0.498	
Poland	0.504	0.494	0.010	0.003	0.485	0.498	
Portugal	0.503	0.495	0.008	0.003	0.487	0.499	
Romania	0.506	0.491	0.014	0.004	0.478	0.498	
Slovakia	0.502	0.496	0.006	0.002	0.491	0.499	

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Slovenia	0.502	0.497	0.005	0.002	0.492	0.499
Spain	0.504	0.493	0.011	0.003	0.483	0.499
Sweden	0.608	0.139	0.468	0.176	-0.262	0.304
United Kingdom	0.503	0.496	0.007	0.002	0.489	0.499

Country	Score original	Bias corrected	bias	std	lower	upper	2012
Austria	0.529	0.459	0.071	0.027	0.395	0.497	
Belgium	0.508	0.488	0.020	0.007	0.469	0.498	
Bulgaria	0.501	0.498	0.003	0.001	0.495	0.499	
Croatia	0.514	0.478	0.037	0.011	0.444	0.494	
Cyprus	0.502	0.497	0.006	0.002	0.491	0.499	
Czechia	0.529	0.454	0.076	0.022	0.385	0.486	
Denmark	0.588	0.375	0.213	0.079	0.183	0.488	
Estonia	0.501	0.499	0.002	0.001	0.497	0.500	
Finland	0.503	0.495	0.008	0.002	0.488	0.499	
France	0.510	0.485	0.025	0.008	0.462	0.497	
Germany	0.503	0.495	0.008	0.003	0.488	0.499	
Greece	0.502	0.497	0.004	0.001	0.494	0.499	
Hungary	1.000	-0.306	1.306	0.383	-1.494	0.244	
Ireland	0.506	0.492	0.014	0.005	0.479	0.498	
Italy	0.507	0.489	0.018	0.006	0.472	0.498	
Latvia	0.507	0.491	0.016	0.006	0.477	0.499	
Lithuania	0.502	0.497	0.005	0.002	0.492	0.499	
Luxembourg	1.000	-0.279	1.279	0.347	-1.133	0.273	
Malta	0.502	0.497	0.005	0.001	0.492	0.499	
Netherlands	0.507	0.489	0.018	0.006	0.472	0.498	
Poland	0.504	0.494	0.010	0.003	0.485	0.498	
Portugal	0.503	0.496	0.007	0.002	0.489	0.499	
Romania	0.505	0.492	0.013	0.004	0.480	0.498	
Slovakia	0.502	0.497	0.006	0.002	0.491	0.499	
Slovenia	0.502	0.497	0.004	0.001	0.493	0.499	
Spain	0.503	0.495	0.008	0.002	0.488	0.499	
Sweden	0.622	0.190	0.431	0.170	-0.212	0.349	
United Kingdom	0.503	0.496	0.007	0.002	0.490	0.499	

Country	Score original	Bias corrected	bias	std	lower	upper	2014
Austria	0.531	0.459	0.072	0.031	0.395	0.500	
Belgium	0.507	0.489	0.018	0.006	0.472	0.497	
Bulgaria	0.501	0.498	0.003	0.001	0.495	0.499	

Croatia	0.513	0.480	0.033	0.010	0.450	0.494
Cyprus	0.502	0.497	0.005	0.001	0.493	0.499
Czechia	0.528	0.456	0.072	0.022	0.391	0.487
Denmark	0.604	0.358	0.246	0.098	0.136	0.491
Estonia	0.501	0.499	0.002	0.001	0.497	0.500
Finland	0.503	0.495	0.008	0.002	0.489	0.499
France	0.512	0.482	0.030	0.009	0.454	0.496
Germany	0.503	0.496	0.007	0.002	0.490	0.499
Greece	0.502	0.498	0.004	0.001	0.494	0.499
Hungary	1.000	-0.297	1.297	0.396	-1.475	0.270
Ireland	0.506	0.491	0.016	0.005	0.476	0.498
Italy	0.507	0.489	0.019	0.006	0.471	0.497
Latvia	0.507	0.491	0.015	0.007	0.477	0.500
Lithuania	0.502	0.496	0.006	0.002	0.491	0.499
Luxembourg	1.000	-0.117	1.117	0.458	-1.106	0.465
Malta	0.502	0.497	0.006	0.002	0.491	0.499
Netherlands	0.506	0.491	0.016	0.005	0.476	0.498
Poland	0.503	0.495	0.009	0.003	0.486	0.498
Portugal	0.502	0.496	0.006	0.002	0.490	0.499
Romania	0.505	0.492	0.014	0.004	0.479	0.498
Slovakia	0.502	0.496	0.006	0.002	0.491	0.499
Slovenia	0.502	0.497	0.005	0.001	0.493	0.499
Spain	0.503	0.496	0.007	0.002	0.489	0.499
Sweden	0.665	0.277	0.389	0.162	-0.073	0.489
United Kingdom	0.503	0.496	0.007	0.002	0.489	0.499

Country	**Score original**	**Bias corrected**	**bias**	**std**	**lower**	**upper**	**2016**
Austria	0.527	0.460	0.067	0.022	0.401	0.489	
Belgium	0.506	0.491	0.015	0.004	0.478	0.496	
Bulgaria	0.501	0.498	0.004	0.001	0.495	0.499	
Croatia	0.513	0.479	0.034	0.009	0.450	0.492	
Cyprus	0.502	0.497	0.005	0.001	0.493	0.499	
Czechia	0.530	0.451	0.079	0.021	0.382	0.480	
Denmark	0.572	0.392	0.180	0.056	0.235	0.469	
Estonia	0.501	0.499	0.002	0.001	0.497	0.500	
Finland	0.503	0.495	0.008	0.002	0.488	0.498	
France	0.510	0.484	0.025	0.007	0.462	0.493	
Germany	0.503	0.496	0.007	0.002	0.490	0.498	
Greece	0.502	0.497	0.004	0.001	0.494	0.499	
Hungary	1.000	-0.322	1.322	0.350	-1.482	0.148	

Ireland	0.507	0.489	0.018	0.005	0.473	0.496
Italy	0.506	0.490	0.016	0.004	0.476	0.496
Latvia	0.503	0.495	0.008	0.003	0.488	0.499
Lithuania	0.502	0.497	0.006	0.002	0.492	0.499
Luxembourg	0.824	0.070	0.754	0.258	-0.607	0.376
Malta	0.505	0.493	0.012	0.003	0.482	0.497
Netherlands	0.505	0.492	0.013	0.003	0.481	0.497
Poland	0.504	0.494	0.009	0.003	0.486	0.498
Portugal	0.502	0.496	0.006	0.002	0.490	0.499
Romania	0.506	0.490	0.017	0.005	0.475	0.496
Slovakia	0.502	0.496	0.006	0.002	0.491	0.498
Slovenia	0.502	0.496	0.006	0.002	0.491	0.499
Spain	0.503	0.495	0.007	0.002	0.489	0.498
Sweden	0.606	0.211	0.395	0.140	-0.149	0.360
United Kingdom	0.503	0.495	0.008	0.002	0.488	0.498

Appendix 2

Table 2.1: Published journal research papers (Total 6) and citations (Total 21) (Data updated 12/11/2019)

Full title	Times Cited and citations	Year
Halkos, G. and Petrou, K.N. (2019) Analysing the Energy Efficiency of EU Member States: The Potential of Energy Recovery from Waste in the Circular Economy. *Energies*, 12(19), 3718.	1 citation: 1. Wang, Q., Li, D. and Chang, T.H. (2019) Energy and Health Efficiencies in China with the Inclusion of Technological Innovation. International Journal of Environmental Research and Public Health, 16.	2019
Halkos, G. and Petrou, K.N. (2019) Evaluating 22 EU Member States' 'waste culture' using Hofstede's and Schwartz's cultural dimensions. *International Journal of Sustainable Development & World Ecology*, 26(4), 313-328.		2019
Halkos, G. and Petrou, K.N. (2019) Treating undesirable outputs in DEA: A critical review. *Economic Analysis and Policy*, 62, 97-104.	5 citations: 1. Chen, L., Huang, Y., Li, M.-J. and Wang, Y.-M. (2020) Meta-frontier analysis using cross-efficiency method for performance evaluation. *European Journal of Operational Research*, 280(1), 219-229. 2. Li, G.L. (2019) Spatiotemporal Dynamics of Ecological Total-Factor Energy Efficiency and Their Drivers in China at the	2019

	Prefecture Level. *International Journal of Environmental Research and Public Health*, 16. 3. Afzalinejad, M. (2019) Reverse efficiency measures for environmental assessment in data envelopment analysis. *Socio-Economic Planning Sciences*, In Press. 4. Zhou, Z., Jin, Q., Peng, J., Xiao, H. and Wu, S. (2019) Further Study of the DEA-Based Framework for Performance Evaluation of Competing Crude Oil Prices' Volatility Forecasting Models. *Mathematics*, 7, 827. 5. Aranda Alba, A.J. (2019) Análisis dinámico de la eficiencia: una aplicación a la Superliga Europea. (Trabajo Fin de Grado Inédito). Universidad de Sevilla, Sevilla.	
Halkos, G. and Petrou, K.N. (2018) Assessing 28 EU member states' environmental efficiency in national waste generation with DEA. *Journal of Cleaner Production*, 208, 509-521.	9 citations: 1. Liu, X., Guo, P. and Nie, L. (2020) Applying emergy and decoupling analysis to assess the sustainability of China's coal mining area. *Journal of Cleaner Production*, 243.	2018

	2. Sun, J., Ruze, N., Zhang, J., Zhao, H. and Shen, B. (2019) Evaluating the Investment Efficiency of China's Provincial Power Grid Enterprises under New Electricity Market Reform: Empirical Evidence Based on Three-Stage DEA Model. *Energies*, 12(18), 3524. 3. Zinovyeva, I.S., Savin, A.G., Brizhak, O.V. and Shchinova, R.A. (2019) Natural Management of a Modern Region: assessment of Effectiveness and Perspectives of Improvement. *Growth Poles of the Global Economy: Emergence, Changes and Future Perspectives*, 73, 717-723. 4. Kiavi Mavi, N. and Kiavi Mavi, R. (2019) Energy and environmental efficiency of OECD countries in the context of the circular economy: Common weight analysis for malmquist productivity index. *Journal of Environmental Management,* 247(1), 651-661. 5. Wang, X., Shao, Q., Nathwani, J. and Zhou, Q. (2019) Measuring wellbeing performance of carbon emissions using	

	hybrid measure and meta-frontier techniques: Empirical tests for G20 countries and implications for China. *Journal of Cleaner Production*, 237, 117758. 6. Wang, X., Zhang, M., Nathwani, J. and Yang, F. (2019) Measuring Environmental Efficiency through the Lens of Technology Heterogeneity: A Comparative Study between China and the G20. *Sustainability*, 11, 461 7. Mesjasz-Lech, A. and Michelberger, P. (2019) Sustainable Waste Logistics and the Development of Trade in Recyclable Raw Materials in Poland and Hungary. *Sustainability*, 11, 4159. 8. Zhu, W., Xu, L., Tang, L. and Xiang, X. (2019) Eco-efficiency of the Western Taiwan Straits Economic Zone: An evaluation based on a novel eco-efficiency model and empirical analysis of influencing factors. *Journal of Cleaner Production*, 234, 638-652.	

	9. Zhou, A., Wu, S., Chu, Z. and Huang, W.-C. (2019) Regional Differences in Municipal Solid Waste Collection Quantities in China. *Sustainability*, 11, 4113.	
Halkos, G. and Petrou, K.N. (2017) Assessing Waste Generation Efficiency in EU Regions towards Sustainable Environmental Policies. *Sustainable Development*, 26(3), 281-301.	<u>4 citations:</u> 1. Tan, Y., Shuai, C., Jiao, L. and Shen, L. (2018) Adaptive neuro-fuzzy inference system approach for urban sustainability assessment: A China case study. *Sustainable Development*, 26(6), 749-764. 2. Callao, C., Martinez-Nunez, M. and Latorre, M.P. (2019) European Countries: Does common legislation guarantee better hazardous waste performance for European Union member states? *Waste Management*, 84, 147-157. 3. Lin, F., Lin, SW. and Lu, W.M. (2019) Dynamic eco-efficiency evaluation of the semiconductor industry: a sustainable development perspective. *Environmental Monitoring and Assessment*, 191-435.	2017

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

	4. Macias Lam, L.M., Paez Bernal, M.A. and Torres Acosta, G. (2018) La Gestión Integral de Residuos Sólidos Urbanos desde una perspectiva territorial en el estado de Hidalgo y sus municipios. Centro Público de Investigación CONACYT, Mexico.	
Halkos, G. and Petrou K.N. (2016) Moving Towards a Circular Economy: Rethinking Waste Management Practices. Journal of Economic and Social Thought, 3(2), 220-240.	2 citations: 1. Kaza, S., Yao, L., Bhada-Tata, P. and Van Woerden, F. (2018) What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. World Bank, 115 – 140. 2. Skorupskaitė, K. and Junevičius, A. (2017) Waste Management Policy Development in Lithuania Applying Circular Economy Model. *Public Policy and Administration*, 16(1), 91-107	2016

Table 2.2: MPRA published papers (Total 5) and citations (Total 5) (Data updated 12/11/2019)

Full title	**Times Cited and citations**	**Year**
Halkos, G. and Petrou, K.N. (2018) 'Waste culture' assessment using Hofstede's and Schwartz's cultural dimensions – an EU case study. MPRA Paper No. 90506, Posted 13 December 2018.		2018
Halkos, G. and Petrou, K.N. (2018) A critical review of the main methods to treat undesirable outputs in DEA. MPRA Paper No. 90374, Posted 5 December 2018.		2018
Halkos, G. and Petrou, K.N. (2018) Assessment of national waste generation in EU Member States' efficiency. MPRA Paper No. 84590, Posted 3 February 2018.	<u>1 citation:</u> 1. Margallo, M., Cobo, S., Laso, J., Fernandez, A., Munoz, E., Santos, E., Alcado, R. and Irabien, A. (2019) Environmental performance of alternatives to treat fly ash from a waste to energy plant. *Journal of Cleaner Production*, 231, 1016-1026	2018
Halkos, G. and Petrou, K.N. (2017) Regional environmental efficiency in waste generation. MPRA Paper No. 81237, Posted 9 September 2017.		2017
Halkos, G. and Petrou, K.N. (2016) Efficient waste management practices: A review. MPRA Paper No. 71518, Posted: 21 May 2016.	<u>4 citations:</u>	2016

	1. Waqas, M. (2019) The Current Status and Steps Towards Sustainable Waste Management in the Developing Countries: A Case Study of Peshawar-Pakistan. *Indonesian Journal of Urban and Environmental Technology*, 3(1). 2. Li, M., Luo, N. and Lu, Y. (2017) Biomass Energy Technological Paradigm (BETP): Trends in This Sector. *Sustainability,* 9, 567. 3. Charis, G., Danha, G. and Muzenda, E. (2019) Waste valorisation opportunities for bush encroacher biomass in savannah ecosystems: A comparative case analysis of Botswana and Namibia. *Procedia Manufacturing*, 35, 974-979. 4. Gaol, M.L. (2017) Life Cycle Assessment (LCA) Pengelolaan Sampah pada Tempat Pemrosesan Akhir (TPA) Sampah (Studi Kasus: TPA Jabon, Kabupaten Sidoarjo). Undergraduate thesis, Institut Teknologi Sepuluh Nopember.	

References

Abrate, G. and Ferraris, M. (2010) The Environmental Kuznets Curve in the Municipal Solid Waste Sector. Hermes, Working Paper n. 1.

Adler, N. and Golany, B. (2001) Evaluation of deregulated airline networks using data envelopment analysis combined with principal component analysis with an application to Western Europe. *European Journal of Operational Research*, 132(2), 260-273.

Ahmeda, S.A. & Alib, M. (2004) Partnerships for solid waste management in developing countries: linking theories to realities. *Journal of Habitat International*, 28(3), 467–479.

Aini, M.S., Fakhru'l-Razi, A., Lad, S.M. and Hashim, A.H. (2002) Practices, attitudes and motives for domestic waste recycling. *International Journal of Sustainable Development & World Ecology*, 9(3), 232-238.

Akaike, H. (1974) A new look at the statistical model identification. *IEEE Transactions on Automatic Control AC*, 19, 716–723.

Alfredsson, E., Månsson, J. and Vikström, P. (2016) Internalising external environmental effects in efficiency analysis: The Swedish pulp and paper industry 2000–2007. *Economic Analysis and Policy*, 51,22–31.

Ali, A.I. and Seiford, L.M. (1990) Translation-invariance in data envelopment analysis. *Operations Research Letters*, 9(6), 403-405.

Amado, C.A.F., Santos, S.P. and Marques, P.M. (2012) Integrating the Data Envelopment Analysis and the Balanced Scorecard approaches for enhanced performance assessment. *Omega*, 40(3), 390-403.

Amirteimoori, A., Kordrostami, S. and Sarparast, M. (2006) Modeling undesirable factors in data envelopment analysis. *Applied Mathematics and Computatio*n, 180(2), 444–452.

Andrews, E. (2008) Effectiveness of Environmental Education Programs. University of Wisconsin, Environmental Resources Center.

Angelis-Dimakis, A., Biberacher, M., Dominguez, J., Fiorese, G., Gadocha, S., Gnansounou, E., Guariso, G., Kartalidis, A., Panichelli, L., Pinedo, I. and Robba, M. (2011) Methods and tools to evaluate the availability of renewable energy sources. *Renewable and Sustainable Energy Reviews,* 15, 1182–1200.

Ansuategi, A., Barbier, E.B. and Perrings C.A. (1998) The Environmental Kuznets Curve, in van den Bergh, J.C.J.M. and Hofkes, M.W. (eds), Theory and Implementation of Economic Models for Sustainable Development, Kluwer.

Apergis, N. and Payne, J.E. (2010) Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. *Energy Policy*, 38, 656–660.

Aravossis, K., Anagnostopoulos, P., Kungolos, A. and Vliamos, S. (2001) A New Methodology Approach for the Technical economical Evaluation of Alternative Waste Disposal Methods by use of Multicriteria Analysis. *Proceedings of the 7th International Conference on Environmental Science and Technology*, p. 40 – 51.

Arcelus, F.J. and Arocena, P. (2005) Productivity differences across OECD countries in the presence of environmental constraints. *Journal of Operational Research and Society*, 56, 1352–1362.

Arellano, M.M. and Bond, S. (1988) Dynamic Panel Data Estimation Using DPD-a Guide for Users. Institute for Fiscal Studies, Working Paper Series.

Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C.S., Jansson, B.O., Levin, S., Mäler, K.G., Perrings, C. and Pimentel, D. (1995) Economic growth, carrying capacity and the environment. *Science*, 268, 520–521.

Aydin, C. and Esen, O. (2017) The Validity of the Environmental Kuznets Curve Hypothesis for CO_2 Emissions in Turkey: New Evidence from Smooth Transition Regression Approach. *Journal of Social Sciences Institute,* 14(39), 101-116.

Bakopoulou, S. and Kungolos, A. (2004) Waste management in Larissa prefecture, Greece. In: Waste Management and the Environment II, Popov, V., Itoh, H.,. Brebbia, C.A. and Kungolos, A. (Eds), WIT Press, Southampton, UK.

Balestra, P. and Nerlove, M. (1966) Pooling cross-section and time series data in the estimation of a dynamic model: the demand for natural gas. *Econometrica*, 34, 585–612.

Ball, V.E., Lovell, C.K., Luu, H., Nehring, R. (2004) Incorporating environmental impacts in the measurement of agricultural productivity growth. *Journal of Agricultural and Resource Economics*, 29(3), 436-460.

Baltagi, B.H. and Pesaran, H. (2007) Heterogeneity and Cross Section Dependence in Panel Data Models: Theory and Applications. *Journal of Applied Econometrics*, 22, 229–232.

Banker, R. D., Charnes, A. and Cooper, W.W. (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 30, 1078–1092.

Banker, R.D., Charnes, A, Cooper W.W., Swarts, J., Thomas, D. (1989) An introduction to data envelopment analysis with some of its models and their uses. *Research in Government and Nonprofit Accounting*, 5, 125–163.

Barba-Gutiérrez, Y., Adenso-Díaz, B. and Lozano, S. (2008) Eco-Efficiency of Electric and Electronic Appliances: A Data Envelopment Analysis (DEA). *Environmental Modeling & Assessment*, 14(4), 439-447.

Barros, C.P., Managi, S. and Matousek, R. (2012) The technical efficiency of the Japanese banks: non-radial directional performance measurement with undesirable outputs. *Omega*, 40, 1–8.

Basak, G.K. and Das, S. (2018) Understanding Cross-Sectional Dependence in Panel Data. *SSRN online*, Available at. [Accessed: 10 September 2019]

Batool, S.A. & Ch, M.N. (2009) Municipal solid waste management in Lahore city district, Pakistan. *Waste Management*, 29, 1971–1981.

Bator, R.J. and Cialdini, R.B. (2000) The application of persuasion theory to the development of effective pro-environmental public service announcements. *Journal of Social Issues*, 56, 527–541.

Baumann, H. and Tillman, A.M. (2004) The hitch hiker's guide to LCA: an orientation in life cycle assessment methodology and application. Lund: Studentlitteratur.

Belgiorno, V., De Feo, G., Della Rocca, C. and Napoli, R.M.A. (2003) Energy from gasification of solid wastes. *Waste Management*, 23(1), 1-15.

Benito, B., Bastida, F. and García, J. A. (2010) The determinants of efficiency in municipal governments. *Applied Economics*, 42(4), 515–528.

Berg, S.A., Forsund, F.R. and Jansen, E.S. (1992) Malmquist indices of productivity growth during the deregulation of Norwegian banking 1980–1989. *Scandinavian Journal of Economics,* 94(0), 211–228.

Berkun, M., Aras, E. & Nemlioglu, S. (2005) Disposal of solid waste in Istanbul and along the black sea coast of Turkey. *Waste Management*, 25(8), 847–855.

Berndtsson, M. (2015) Circular Economy and Sustainable Development. Master thesis in Sustainable Development at Uppsala University. Available at. [Accessed: 18 April 2017]

Bhuiyan, S.H. (2010) A crisis in governance: Urban solid waste management in Bangladesh. *Habitat International*, 34(1), 125–133.

Bian, Y.W. and Fang, Y. (2010) Resource and environment efficiency analysis of provinces in China: A DEA approach based on Shannon’s entropy. *Energy Policy*, 38, 1909–1917.

Bollen, K.A. and Brand, J.E. (2011) A General Panel Model with Random and Fixed Effects: A Structural Equations Approach. *Social Forces*, 89(1), 1-34.

Bond, M. H. (1988) Finding universal dimensions of individual variation in multicultural studies of values: The Rokeach and Chinese value surveys. *Journal of Personality and Social Psychology*, 55(6), 1009-1015.

Bosch, N., Pedraja, F. and Suárez-Pandiello, J. (2000) Measuring the efficiency of Spanish municipal refuse collection services. *Local Government Studies*, 26(3), 71–90.

Boussofiane, A., Dyson, R.G. and Thanassoulis, E. (1991) Applied data envelopment analysis. *European Journal of Operational Research,* 52, 1–15.

Bramryd, T., Hogland, W., Marques, M. & Nimmermarks, S., (1999) Optimised Composting of Source-separated Organic Fractions of Household Waste in A Vertically Fed Reactor System. In: SARDINIA´99, *Seventh International Waste Management and Landfill Symposium*, 4-8 October 1999, Cagliari, Italy, Proceedings Vol. V: 391-398.

Bratt, C. (1999) The impact of norms and assumed consequences on recycling behavior. *Environmental Behaviour*, 31, 630–656.

Breitung, J. (2000) The local power of some unit root tests for panel data. In: Nonstationary panels, Panel cointegration, and Dynamic panels, Baltagi, B.H. (Ed.), Elsevier, Amsterdam, 161-177.

Breitung, J. and Das. S. (2005) Panel unit root tests under cross sectional dependence. *Statistica Neerlandica*, 59(4), 414-433.

Brett, J. M. and Okumura, T. (1998) Inter- and intracultural negotiation: US and Japanese negotiators. *Academy of Management Journal*, 41(5), 495–510.

Bridgwater, A.V. (2012) Review of fast pyrolysis of biomass and product upgrading. *Biomass & Bioenergy*, 38, 68-94.

Bridgwater, A.V. and Peacocke, G.V. (2000) Fast pyrolysis processes for biomass. *Renewable and Sustainable Energy Reviews*, 4(1), 1-73.

Callan, S.J. and Thomas, J.M. (1997) The Impact of State and Local Policies on the Recycling Effort. *Eastern Economic Journal*, 23(4), 411-423.

Camarero, J.J., Bigler, C., Linares, J.C. and Gil-Pelegrin, E. (2011) Synergistic effects of past historical logging and drought on the decline of Pyrenean silver fir forests. *Forest Ecology and Management*, 262, 759–769.

CEWEP (2017) Waste to energy plants in Europe in 2017. Available at. [Accessed: 17 September 2019]

Chang, N.B., Pires, A. & Martinho, G. (2011) Empowering systems analysis for solid waste management: trends and perspectives. *Critical Reviews in Environmental Science and Technology*, 41(16), 1449-1530.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) Measuring the efficiency of decision making units. *European Journal of Operational Research,* 2, 429–444.

Chekima, B., Chekima, S., Syed Khalid Wafa, A.W., Igau, O.A., Sondoh, S.L. (2016) Sustainable consumption: the effects of knowledge, cultural values, environmental advertising, and demographics. *International Journal of Sustainable Development & World Ecology*, 23(2), 210-220.

Chen, C.C. (2010) Spatial inequality in municipal solid waste disposal across regions in developing countries. *International Journal of Environmental Science and Technology*, 7(3), 447-456.

Chen, T. and Hu, J.-L. (2007) Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. *Energy Policy*, 35, 3606–3615.

Chen, C., Zhu, J., Yu, J-Y. and Noori, H. (2012) A new methodology for evaluating sustainable product design performance with two-stage network data envelopment analysis. *European Journal of Operational Research*, 221, 348–359.

Chen, H.-W., Chang, N.-B., Chen, J.-C. and Tsai, S.-J. (2010) Environmental performance evaluation of large-scale municipal solid waste incinerators using data envelopment analysis. *Waste Management,* 30, 1371–1381.

Chen, P.-C., Yu, M.-M., Chang, C.-C. and Managi, S. (2014) Non-Radial Directional Performance Measurement with Undesirable Outputs. MPRA Paper, No. 57189, posted 9. July 2014.

Chen, P.-C., Yu, M.-M., Chang, C.-C., Hsu, S.-H. and Managi, S. (2015) The enhanced Russell-based directional distance measure with undesirable outputs: Numerical example considering CO_2 emissions. *Omega*, 53, 30-40.

Chen, Y. and Chen, C., (2012) The privatization effect of MSW incineration services by using data envelopment analysis. *Waste Management,* 32, 595–602.

Cheng, G. and Zervopoulos, P. (2014) Estimating the technical efficiency of health care systems: a cross country comparison using the directional distance function. *European Journal of Operational Research*, 238, 899–910.

Cherchye, L., Moesen, W., Rogge, N. and Van Puyenbroeck, T. (2007) An introduction to Benefit of the doubt composite indicators. *Social Indicators Research*, 82(1), 111-145.

Chien, T. and Hu, J.-L. (2007) Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. *Energy Policy*, 35, 3606–3615.

Choi, Y., Zhang, N. and Zhou, P. (2012) Efficiency and abatement costs of energy-related CO_2 emissions in China: a slacks-based efficiency measure. Applied *Energy*, 98, 198–208.

Chung, S.S. & Lo, C.W. (2008) Local waste management constraints and waste administrators in China. *Waste Management*, 28(2), 272–281.

Chung, Y.H., Färe, R., Grosskopf, S. (1997) Productivity and undesirable outputs: A directional distance function approach. *Journal of Environmental Management*, 51(3), 229-240.

Coelli, T.J., Rao, D.S.P., O' Donell, C.J., Battese, G.E. (2005) An Introduction to Efficiency and Productivity Analysis. Springer, New York, USA.

Cole, M.A., Rayner, A.J. and Bates, J.M (1997) The Environmental Kuznets Curve: an empirical analysis. *Environment and Development Economics*, 2, 401–416.

Coggins, J.S. and Swinton, J.R. (1996) The Price of Pollution: A Dual Approach to Valuing SO2 Allowances. *Journal of Environmental Economics and Management*, 30, 58 – 72.

Cook, W.D., Tone, K. and Zhu, J. (2014) Data envelopment analysis: Prior to choosing a model. *Omega*, 44, 1–4.

Cooper, W. W., Seiford, L. M. and Zhu, J. (Eds.) (2011) Handbook on data envelopment analysis (2nd ed.). New York, NY: *Springer Science and Business Media*.

Cropper, M.L. and Oates, W.E. (1992) Environmental economics: a survey. *Journal of Economic Literature*, 30, 675–740.

Dahlén, L. and Lagerkvist, A. (2008) Methods for household waste composition studies. *Waste Management*, 28(7), 1100–1112.

Dasgupta, S., Laplante, B., Wang, H. and Wheeler, D. (2002) Confronting the Environmental Kuznets Curve. *Journal of Economic Perspectives*, 16(1), 147–168.

Defra (2011a) The Economics of Waste and Waste Policy, Waste Economics Team, Environment and Growth Economics, Department for Environment, Food and Rural Affairs. This document is available on the Defra website. [Accessed: 19 December 2015]

Defra (2011b) Guidance on applying the Waste Hierarchy. Department for Environment, Food and Rural Affairs. This document is available on the Defra website. [Accessed: 19 December 2015]

Defra (2013a) Mechanical Biological Treatment of Municipal Solid Waste. Department for Environment, Food and Rural Affairs. This document is available on the Defra website. [Accessed: 28 December 2015]

Defra (2013b) Incineration of Municipal Solid Waste. Department for Environment, Food and Rural Affairs. This document is available on the Defra website. [Accessed: 28 December 2015]

Defra, DECC and NNFCC (2016) The Official Information Portal on Anaerobic Digestion, Available at. http://www.biogas-info.co.uk/ [Accessed: 10 March 2016].

Demetriades, P. and James, G.A. (2011) Finance and Growth in Africa: The Broken Link. *Economics Letters*, 113(3), 263-265.

Derimbas, A. and Arin, G. (2002) An Overview of Biomass Pyrolysis. *Energy Sources*, 24(5), 471-482.

de Beer, J., Cihlar, J., Hensing, I. and Zabeti, M. (2017) Status and prospects of co-processing of waste in EU cement plants. Ecofys publication.

De Bruyn, S.M., van den Bergh, J.C.J.M. and Opschoor, J.B. (1998) Economic growth and emissions: reconsidering the empirical basis of Environmental Kuznets Curves. *Ecological Economics*, 25, 161-175.

De Feo, G. and De Gisi, S. (2010) Domestic Separation and Collection of Municipal Solid Waste: Opinion and Awareness of Citizens and Workers. *Sustainability*, 2(5), 1297-1326.

De Feo, G. and Napoli, R.M.A. (2005) New and old paradigms on production and management of municipal solid waste. In Proceedings of Sardinia 2005, Tenth International Waste Management and Landfill Symposium, Cagliari, Italy, 3–7 October 2005; CISA: Cagliari, Italy.

De Jaeger, S., Eyckmans, J., Rogge, N. and Van Puyenbroeck, T. (2011) Wasteful waste reducing policies? The impact of waste reduction policy instruments on collection and processing costs of municipal solid waste. *Waste Management*, 31, 1429–1440.

De Kadt, M. (1994) Garbage Culture and The Culture of Garbage: The Solid Waste Management Quagmire. *Organization and Environment*, 8(4), 345-379.

De Koeijer, T.J., Wossink, G.A.A., Struik, P.C. and Renkema, J.A. (2002) Measuring agricultural sustainability in terms of efficiency: the case of Dutch sugar beet growers. *Journal of Environmental Management*, 66, 9–17.

Dickey, D.A. and Fuller, W.A. (1981) Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica*, 49, 1057-1072.

Dinda S., D. Coondos and M. Pal (2000) Air quality and economic growth: an empirical study. *Ecological Economics*, 34, 409-423.

Dinda, S. (2004) Environmental Kuznets Curve Hypothesis: A Survey. *Ecological Economics*, 49(4), 431-455.

Dostalova, K. (2014) Efficiency Evaluation of Municipal Solid Waste Management in the Czech Republic using DEA Method. *Master Thesis*, Masaryk University, Faculty of Economics and Administration, Brno.

Drogendijka, R. and Slangen, A. (2006) Hofstede, Schwartz, or managerial perceptions? The effects of different cultural distance measures on establishment mode choices by multinational enterprises. *International Business Review*, 15, 361–380.

Droste, N., Lima, G. R., May, P. H., and Ring, I. (2017) Municipal Responses to Ecological Fiscal Transfers in Brazil: A microeconometric panel data approach. *Environmental Policy and Governance*, 27, 378–393.

Duggal, Vijaya G., Saltzman, C. and Williams, Mary L. (1991) Recycling: An Economic Analysis. *Eastern Economic Journal,* XVII (3).

Dyckhoff, H. and Allen, K. (2001) Measuring ecological efficiency with data envelopment analysis (DEA). *European Journal of Operational Research*, 132, 312-325.

Dyson, R.G. and Shale, E.A. (2010). Data envelopment analysis, operational research and Uncertainty. *Journal of the Operational Research Society*, 61, 25—34.

Edjabou M.E., Jensen, M.B., Götze, R., Pivnenko, K., Petersen, C., Scheutz, C. & Astrup, T.F. (2015) Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation. *Waste Management*, 36, 12–23.

Efron, B. (1979) Bootstrap methods: another look at the jackknife. *Annals of Statistics*, 7, 1-26.

El Leithy, W. (2017) A Review of the Impact of National Culture on Economic Growth. *International Journal of Economics & Management Science*, 6(4), 1-4.

Elliott, P., Eaton, N., Shaddick, G. & Carter, R. (2000) Cancer incidence near municipal solid waste incinerators in Great Britain. Part 2: histopathological and case-note review of primary liver cancer cases. *British Journal of Cancer*, 82, 1103–1106.

Environment Agency (2002) Processes and Plant for Waste Composting and other Aerobic Treatment, R&D Technical Report P1-311/TR.

EPA (2016) Recycling basics. US Environmental Protection Agency. Available at. [Accessed: 5 April 2016]

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Eunomia (2015) Economic Analysis of Options for Managing Biodegradable Municipal Waste, Final Report to the European Commission. Available at. [Accessed: 15 December 2016]

European Commission (1999). Directive 1999/31/EC on the landfill of waste. European Commission, Official Journal of the European Communities, Council of the European Union L182/1, 19.

European Commission (2004) Methodology for the Analysis of Solid Waste (SWAtool), User Version 43, 1–57.

European Commission (2008) Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance), OJ L 312, 22.11.2008, 3–30.

European Commission (2010a) Being wise with waste: the EU's approach to waste management. European Commission, Luxembourg: Publications Office of the European Union.

European Commission (2010b) EUROPE 2020: A European strategy for smart, sustainable and inclusive growth. European Commission, Communication from the Commission. Available at. [Accessed: 15 December 2015]

European Commission (2012a) Guidance on municipal waste data collection, European Commission Eurostat – Directorate E: Sectoral and regional statistics Unit E3 – Environment and forestry.

European Commission (2012b) Energy and environment – Overview. Available at.

European Commission (2015a) EU Waste Legislation. European Commission, Environnent. Available at. [Accessed: 10 December 2015]

European Commission (2015b) Directive 2008/98/EC on waste (Waste Framework Directive). European Commission, Environnent. Available at. [Accessed: 8 December 2015]

European Commission (2015c) Overview: making markets work better. Available at.

European Commission (2016a) The road to a circular economy. European Commission, Environnent. Available at. [Accessed: 9 December 2015]

European Commission (2016b) Review of Waste Policy and Legislation. European Commission, Environment. Available at. [Accessed: 17 December 2015]

European Commission (2017a) Waste and Circular Economy. Available at. [Accessed: 5 December 2015]

European Commission (2017b) The Committee of the Regions and the European Investment Bank. Third Report on the State of the Energy Union. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee, The Committee of the Regions and the European Investment Bank, COM(2017) 688 final.

European Commission (2018) A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee, The Committee of the Regions and the European Investment Bank, COM(2018) 773 final.

European Environment Agency (2012) Movements of waste across the EU's internal and external borders. EEA Report, No 7/2012.

European Environment Agency (2015a) Cross-country comparisons: Waste — municipal solid waste generation and management. European Environment Agency, *SOER 2015*. Available at. [Accessed: 27 November 2015]

European Environment Agency (2015b) Waste prevention in Europe — the status in 2014. European Environment Agency. Available at. [Accessed: 30 November 2015]

Eurometrec (2015) Waste Laws. European Metal Trade and Recycling Federation. Available at. [Accessed: 28 November 2015]

Eurostat (2007) Theme: General and Regional Statistics, Collection: Methodologies and working papers. Available at. [Accessed: 5 April 2017]

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Eurostat (2014a) Eurostat regional yearbook 2014. Available at. [Accessed: 7 November 2015]

Eurostat (2014b) Municipal waste generation and treatment, by type of treatment method, Available at. [Accessed: 7 November 2015]

Eurostat (2016) Top 3 types of treatment and the top 3 export and import countries for the top 10 notified non-hazardous waste according to the European LoW classification in 2013. Available at. [Accessed: 25 April 2017]

Eurostat (2017) Municipal waste treatment by type of treatment. Available at. [Accessed: 15 January 2017]

Exposito, A., Velasco, F., 2018. Municipal solid-waste recycling market and the European 2020 Horizon Strategy: a regional efficiency analysis in Spain. *Journal of Cleaner Production*, 172, 938-948.

Fare, R., Grosskopf, S. and Lovell, C.A.K. (1989) Multilateral productivity comparisons when some outputs are undesirable: a non-parametric approach. *The Review of Economics and Statistics*, 71(1), 90–98.

Fare, R., Grosskopf, S., Lovell, C.A.K. and Yaiswarng, S. (1993) Deviation of shadow prices for undesirable outputs: a distance function approach. *The Review of Economics and Statistics*, 75(2), 374–380.

Fare, R., Grosskopf, S. and Zaim, O. (2000) An index number approach to measuring environmental performance: An environmental Kuznets curve for OECD countries. New Zealand Econometrics Study Group Meeting, University of Canterbury.

Fare, R. and Grosskopf, S. (1995) Environmental decision models with joint outputs. Economics Working Paper Archive, Economic Department, Washington University.

Fare, R., Grosskopf, S. and Hernandez-Sancho, F. (2004) Environmental performance: an index number approach. *Resource and Energy Economics*, 26(4), 343–352.

Färe, R., Grosskop,f S. and Logan, J. (1983) The relative efficiency of Illinois electric utilities. *Resource Energy*, 5, 349–367.

Fare, R., Grosskopf, S., Noh, D.W. and Weber, W. (2005) Characteristics of a polluting technology: theory and practice. *Journal of Econometrics*, 126(2), 469–492.Fare, R. and Grosskopf, S. (2003) Nonparametric productivity analysis with undesirable outputs: comment. *American Journal of Agricultural Economics*, 85(4), 1070–1074.

Fare, R. and Grosskopf, S. (2004) Modelling undesirable factors in efficiency evaluation: Comment. *European Journal of Operational Research*, 157, 242–245.

Fare, R. and Grosskopf, S. (2010) Directional distance functions and slacks-based measures of efficiency. *European Journal of Operational Research*, 200, 320–322.

Farrell, M. J. (1957) The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*, 120(3), 253–290.

Farzipoor Saen, R. (2010) Developing a new data envelopment analysis methodology for supplier selection in the presence of both undesirable outputs and imprecise data. *International Journal of Advanced Manufacturing Technology,* 51(9–12), 1243–1250.

FhG-IBP (2014) Waste 2 Go: D 2.2 Waste Profiling. Prepared by FhG-IBP (Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.) Available at. [Accessed: 28 February 2018]

Fiala, P. (2007) Analýza efektivnosti odpadoveho hospodarství ceských obcí metodou DEA. In: Sauer, P. (Ed.), Príspevky K Metodologii Ex-post Analýz V Politice Zivotního Prostredí II. SEPTIMtisk, Praha, Czech Republic, 87-105.

Fisher, R.A. (1932) Inverse probability and the use of likelihood. *Mathematical Proceedings of the Cambridge Philosophical Society*, 28, 257-261.

Førsund, F. R. and Sarafoglou, N. (2005) The tale of two research communities: The diffusion of research on productive efficiency. *International Journal of Production Economics*, 98(1), 17–40.

Fourie, A. (2006) Municipal solid waste management as a luxury item. *Waste Management,* 26(8), 801–802.

Fredrick, M., Oonyu, J.C. and Sentongo, J. (2018) Influence of Education on the Solid Waste Management Practices of Communities in Kampala City. *Journal of Environment and Waste Management*, 5(1), 261-274.

Fruergaard, T. and Astrup. T. (2011) Optimal utilization of waste-to-energy in an LCA perspective. *Waste Management*, 31, 572–582.

Fukuyama, H. and Weber, W.L. (2010) A slacks-based inefficiency measure for a two-stage system with bad outputs. *Omega* 38(5), 239–410.

Fukuyama, H., Yoshida, Y. and Managi, S. (2011) Modal choice between air and rail: a social efficiency benchmarking analysis that considers CO_2 emissions. *Environmental Economics and Policy Studies*, 13, 89–102.

Fullerton, D. and Kinnaman, Thomas C. (1999) The Economics of Residential Solid Waste Management. Working Paper.

Gallo, A. (2015) A Refresher on Regression Analysis. Harvard Business Review. Available at. [Accessed: 28 August 2019]

Garcia-Perez, M., Shen, J., Wang, S.X. and Li, C.-Z. (2010) Production and fuel properties of fast pyrolysis oil/bio-diesel blends. *Fuel Processing Technology*, 91(3), 296-305.

Gaviao, L.O., Meza, L.A., Lima, G.B.A., Sant'Anna, A.P. and Soares de Mello, J.C.C.B. (2017) Improving discrimination in efficiency analysis of bioethanol Processes. *Journal of Cleaner Production*, 168, 1525-1532.

Geng, Y, Fujita, T., Park, H.-S., Chiu, A.S.F., and Huisingh, D. (2016) Recent progress on innovative eco-industrial development. *Journal of Cleaner Production*, 114, 1-10.

Gnonlonfin, A., Kocoglu, Y. and Péridy, N. (2017) Municipal Solid Waste and Development: The Environmental Kuznets Curve Evidence for Mediterranean Countries. Region et Developpement, Region et Developpement, LEAD, Universite du Sud - Toulon Var, 45, 113-130.

Golany, B. and Roll, Y. (1989) An application procedure for DEA. *Omega*, 17(3), 237–250.

Gomes, E.G. (2003) Modelos de Analise de Envoltoria de Dados com Ganhos de Soma Zero (Zero Sum Gains Data Envelopment Analysis Models). Doctoral thesis, COPPE/Federal University of Rio de Janeiro, Rio de Janeiro, Brazil.

Gomes, E.G. and Lins, M.P.E. (2008) Modelling undesirable outputs with zero sum gains data envelopment analysis models. *Journal of the Operational Research Society*, 59(5), 616 –623.

Gomes, E.G., Soares de Mello, J.C.C.B. and Lins, M.P.E. (2003) Busca sequencial de alvos intermediarios em modelos DEA com soma de outputs constante (Step by step target search in Zero Sum Gains DEA models). *Investigacia Operacional*, 23, 1–16.

Gomes, E.G., Soares de Mello, J.C.C.B. and Lins, M.P.E. (2005) Uniformizacao da fronteira eficiente em modelos de Analise de Envoltoria de Dados com Ganhos de Soma Zero e Retornos Constantes de Escala (Uniform efficient frontier in Zero Sum Gains DEA CCR models). *Pesquisa Operacional*, 25, 261–277.

Grodzinska-Jurczak, M. (2002) The relation between education, knowledge and action for better waste management in Poland. *Waste Management Research*, 21, 2–18.

Grossman, G.M. and Krueger, A.B. (1991) Environmental Impacts of a North American Free Trade Agreement. National Bureau of Economic Research Working Paper 3914, NBER, Cambridge MA.

Grove, C.N. (2015a) Introduction to the GLOBE Research Project on Leadership Worldwide.

Grove, C.N. (2015b) Worldwide Differences in Business Values and Practices: Overview of GLOBE Research Findings.

Guo, D. and Wu, J. (2013) A complete ranking of DMUs with undesirable outputs using restrictions in DEA models. *Mathematical and Computer Modelling*, 58, 1102–1109.

Hadri, K. (2000) Testing for stationarity in heterogeneous panel data. *Econometrics Journal*, 3, 148-161.

Hailu, A. (2003) Non-parametric productivity analysis with undesirable outputs: reply. *American Journal of Agricultural Economics*, 85(4),1075–1077.

Hailu, A. and Veeman, T. (2001) Non-parametric productivity analysis with undesirable outputs: an application to Canadian pulp and paper industry. *American Journal of Agricultural Economics*, 83(3), 605–616.

Halkos, G. (2003) Environmental Kuznets Curve for sulfur: evidence using GMM estimation and random coefficient panel data models. *Environment and Development Economics*, 8, 581–601.

Halkos, G. (2011a) Economy - environment relationship: The case of sulphur emissions. MPRA paper, 45480.

Halkos, G. (2011b) Environment and economic development: determinants of an EKC hypothesis. MPRA paper, 33262.

Halkos, G. (2012) Environmental pollution and economic development: explaining the existence of an environmental Kuznets curve. *Journal of Applied Economic Sciences*, 6(18), 148–159.

Halkos, G. (2013a) Economy and the Environment: Methods of valuation and management. Liberal Books, Athens.

Halkos, G. (2013b) Exploring the economy–environment relationship in the case of sulphur emissions. *Journal of Environmental Planning and Management*, 56(2), 159–177.

Halkos, G. and Papageorgiou, G. (2014) Spatial environmental efficiency indicators in regional waste generation: A nonparametric approach. *DEOS Working Papers 1401*, Athens, University of Economics and Business.

Halkos, G. and Papageorgiou, G. (2015) Spatial environmental efficiency indicators in regional waste generation: A nonparametric approach. *Journal of Environmental Planning and Management*, 59(1), 62-78.

Halkos, G. and Polemis, M.L. (2018) The impact of economic growth on environmental efficiency of the electricity sector: A hybrid window DEA methodology for the USA. Journal of Environmental Management, 211, 334-346.

Halkos, G. and Tzeremes, N. (2009) Exploring the existence of Kuznets curve in countries' environmental efficiency using DEA window analysis. *Ecological Economics*, 68, 2168–2176.

Halkos, G.E. and Tzeremes, N.G. (2012) Analyzing the Greek renewable energy sector: A Data Envelopment Analysis approach. *Renewable and Sustainable Energy Reviews*, 16, 2884– 2893.

Halkos, G. and Tzeremes, N.G. (2013a) Renewable energy consumption and economic efficiency: Evidence from European countries. *Journal of Renewable and Sustainable Energy*, 5, 041803

Halkos, G. and Tzeremes, N. (2013b) National culture and eco-efficiency: an application of conditional partial nonparametric frontiers. *Environmental and Economic Policy Studies*, 15, 423–441.

Halkos, G. and Tzeremes, N. (2013c) Modelling the effect of national culture on countries' innovation performances: A conditional full frontier approach. *International Review of Applied Economics*, 27(5), 656-678.

Hall, D. (2017) Throwaway culture has spread packaging waste worldwide: here's what to do about it. The Guardian, 13 March 2017. Available at. [Accessed: 25 September 2018]

Han X. and Chatterjee L. (1997) Impacts of growth and structural change on CO_2 emissions of developing countries. *World Development*, 25, 395-407.

Han, H. and Zhang, Z. (2017) The impact of the policy of municipal solid waste source-separated collection on waste reduction: a case study of China. *Journal of Material Cycles and Waste Management*, 19, 382–393.

Harris, R.D.F. and Tzavalis, E. (1999) Inference for unit roots in dynamic panels where the time dimension is fixed. *Journal of Econometrics*, 90, 1-44.

Hausman, J.A. (1978) Specification tests in econometrics, *Econometrica*, 46, 1251-1271.

Haynes, S.K.E., Ratick, S., Bowe, S. and Cummings-Saxton, J. (1993) Environmental decision models: US experience and new approach to pollution management. *Environmental International*, 19, 261–275.

He, F., Zhang, Q., Lei, J., Fu, W. and Xu, X. (2013) Energy efficiency and productivity change of China's iron and steel industry: Accounting for undesirable outputs. *Energy Policy*, 54, 204–213.

Higman, C. (2008) Gasification. Chapter 11 In: Combustion Engineering Issues for Solid Fuel Systems, Academic Press, Massachusets, USA.

Hirofumi, F. and William, L.W. (2008) Japanese banking inefficiency and shadow pricing. *Mathematical and Computer Modelling*, 48 (11–12), 1854–1867.

Ho, T.Q., Hoang, V.-N., Wilson, C. and Nguyen, T.-T. (2017) Which farming systems are efficient for Vietnamese coffee farmers?. *Economic Analysis and Policy*, 56, 114-125.

Hofstede, G. (1980) Cultures consequences: international differences in work-related values. Sage Press, Beverly Hills.

Hofstede, G. (1983) The cultural relativity of organizational practices and theories. *Journal of International Business Studies,* 75–90.

Hofstede, G. (1991) Cultures and organizations: software of the mind. London: McGraw-Hill.

Hofstede, G. (2001) Culture's Consequences: Comparing Values, Behaviors, Institutions, and Organizations Across Nations. 2nd ed., Sage, Beverly Hills CA.

Hofstede, G. (2011) Dimensionalizing Cultures: The Hofstede Model in Context. *Online Readings in Psychology and Culture,* 2(1), 1-26.

Hofstede, G. (2018) The 6-D model of national culture. Available at: http://geerthofstede.com/culture-geert-hofstede-gert-jan-hofstede/6d-model-of-national-culture/ [Accessed: 15 January 2018]

Hofstede, G., Hofstede, G.J. and Minkov, M. (2010) Cultures and organizations: software of the mind, 3rd edn. McGraw-Hill, New York.

Hoornweg, D. and Bhada-Tata P. (2012) What a Waste: Waste Management around the World. Washington, DC: World Bank.

Hopper, J.R. and Nielsen, J.M. (1991) Recycling as altruistic behavior: Normative and behavioral strategies to expand participation in community recycling programs. *Environment and Behaviour*, 23, 195–220.

House, R.J., Hanges P.J., Javidan, M., Dorfman, P.W. and Gupta, V. (2004) Culture, Leadership, and Organizations: The GLOBE Study of 62 Societies. SAGE Publications. Google Commerce Ltd.

Hsiao, C. (1986) Analysis of panel data. Econometric society monographs, Vol. 11. Cambridge University Press, New York.

Hsiao, C. (2003) Analysis of Panel Data. Second edition. Cambridge University Press, New York.

Hsiao, C. (2007) Panel data analysis—advantages and challenges. *Test*, 16(1), 1–22.

Hua, Z. and Bian, Y. (2008) Performance measurement for network DEA with undesirable factors. *International Journal of Management and Decision Making*, 9(2), 141–153.

Hua, Z., Bian, Y, and Liang, L. (2007) Eco-efficiency analysis of paper mills along the Huai River: an extended DEA approach. *Omega*. 35(5), 578–587.

Huang, J., Chen, J. and Yin, Z. (2014) A Network DEA Model with Super Efficiency and Undesirable Outputs: An Application to Bank Efficiency in China. *Mathematical Problems in Engineering*, Vol. 2014, Article ID 793192, 14 pages.

Hu, J.L. and Wang, S.C. (2006) Total-factor energy efficiency of regions in China. *Energy Policy*, 34, 3206–3217.

Huang, Y.T., Pan, T.C. and Kao, J.J. (2011) Performance assessment for municipal solid waste collection in Taiwan. *Journal of Environmental Management*, 92(4), 1277-1283.

Iafolla, V., Mazzanti, M. and Nicolli, F. (2010) Are You Sure You Want to Waste Policy Chances? Waste Generation, Landfill Diversion And Environmental Policy Effectiveness in The EU15. Società italiana di economia pubblica, Università di Pavia.

Ichinose, D. and Yamamoto, M. (2011) On the relationship between the provision of waste management service and illegal dumping. *Resource and Energy Economics*, 33(1), 79-93.

Ichinose, D., Yamamoto, M. and Yoshida, Y. (2011) Reexamining the waste-income relationship. GRIPS Policy Research Center, Discussion Paper: 10-31.

ICL (2015) The circular revolution, An Imperial College London report commissioned by Veolia. Available at. [Accessed: 20 February 2017]

Im, K., Pesaran, M.H. and Shin, Y. (2003) Testing for unit roots in heterogeneous panels. *Journal of Economy*, 115, 53–74.

Imam, A., Mohammed, B., Wilson, D.C. & Cheeseman, C.R. (2008) Solid waste management in Abuja, Nigeria. *Waste Management*, 28(2), 468–472.

ISWA (2013) Guidelines: Waste-to-energy in low and middle income countries. International Solid Waste Association, www.iswa.org.

ISWM-Tinos (2012) Deliverable 1-2: European and Greek waste management policies and legislative framework, Development and implementation of a demonstration system on Integrated Solid Waste Management for Tinos in line with the Waste Framework Directive, LIFE 10/ENV/GR/000610. Available at. [Accessed: 19 January 2017]

Jablonský, J. and Dlouhý, M. (2004) Modely hodnocení efektivnosti produkčních jednotek. Praha, Czech Republic: Professional Publishing.

Jahanshahloo, G.R., Lotfi, F.H., Shoja, N., Tohidi, G. and Razavyan, S. (2005) Undesirable inputs and outputs in DEA models. *Applied Mathematics and Computation*, 169(2), 917–925.

Ji, Y. and Lee, C. (2010) Data envelopment analysis. *The Stata journal,* 10(2), 267-280.

Johnstone, N. and Labonne, J. (2004) Generation of Household solid waste in OECD countries. An empirical analysis using macroeconomic data. *Land Economics*, 80(4), 529-538.

Judge, R. and Becker, A. (1993) Motivating Recycling: A Marginal Cost Analysis. *Contemporary Economic Policy*, 11(3), 58-68.

Kabata, T. (2011) The US agriculture greenhouse emissions and environmental performance. In Annual Meeting of the Agricultural Applied Economics Association. Pittsburg, Pennsylvania, 24-26.

Kaika, D. and Zervas, E. (2013) The Environmental Kuznets Curve (EKC) theory—Part A: Concept, causes and the CO_2 emissions case. *Energy Policy*, 62, 1392-1402.

Kao, C. (2014) Network data envelopment analysis: A review. *European Journal of Operational Research,* 239, 1–16.

Kaurosakis K. (2006) MSW generation, disposal and recycling: a note on OECD intercountry differences, paper presented at envecon 2006: Applied Environmental Economics Conference, 24th March 2006, the Royal Society, London.

Khajuria, A., Matsui, T., Machimura, T. and Morioka, T. (2010) Decoupling and Environmental Kuznets Curve for municipal solid waste generation: Evidence from India. *International Journal of Environmental Sciences*, 2(3), 839-843.

Kinnaman, T.C. (2009) The Economics of Municipal Solid Waste Management. *Waste Management*, 2615-2617.

Kinnaman, T.C. and Fullerton, D. (2000) Garbage and recycling with endogenous local policy. *Journal of Urban Economics*, 48, 419–442.

Kleppmann, F. (2013) Current developments in European Waste-to-Energy. Interessengemeinschaft der Thermischen Abfallbehandlungsanlagen Deutschland e.V.

Kogut, B. and Singh, H. (1988) The effect of national culture on the choice of entry mode. *Journal of International Business Studies*, 19(3), 411-432.

Koopmans, T.C. (1951) Analysis of production as an efficient combination of activities. In Koopmans, T. C. (Ed.), Activity analysis of production and allocation (pp. 33–97). New York, NY: John Wiley & Sons.

Kordrostami, S. and Amirteimoori, A. (2005) Un-desirable factors in multi-component performance measurement. *Applied Mathematics and Computation*, 172, 721–729.

Korhonen, P. and Luptacik, M. (2003) Eco-efficiency analysis of power plants: An extension of data envelopment analysis. *European Journal of Operational Research,* 154, 437–446.

Kortelainen, M. and Kuosmanen, T. (2007) Eco-efficiency analysis of consumer durables using absolute shadow prices. *Journal of Productivity Analysis*, 28, 57–69.

Kortelainen, M. (2008) Dynamic environmental performance analysis: a Malmquist index approach. *Ecological Economics*, 64, 701-715.

Krajacic, G., Duic, N., Vujanovic, M., Kilkis, S., Rosen, M.A. and Al-Nimr, M.A. (2016) Sustainable development of energy, water and environment systems for future energy technologies and concepts. *Energy Conversion and Management*, 125, 1–14.

Kumar, S. (2006) Environmentally sensitive productivity growth: A global analysis using Malmquist–Luenberger index. *Ecological Economics*, 56(2), 280–293.

Kumar, S. and Khanna, M. (2002) Productivity growth and CO_2 abatement: A cross-country analysis using the distance function approach. International Conference on Climate Change and Environmental Policy, University of Illinois.

Kumar, S. and Managi, S. (2009) The Economics of Sustainable Development: the Case of India, Springer: New York.

Kungolos, A., Bakopoulou, S. and Papaoikonomou, K. (2006) Planning of solid waste management in Attica prefecture, Greece. *Fresenius Environmental Bulletin*, 12(2), 27-38.

Kungolos, A. (2016) Environmental Engineering: Pollution and environmental protection. Tziolas, Athens, Greece.

Kuosmanen, T. (2005) Weak disposability in nonparametric production analysis with undesirable outputs. *American Journal of Agricultural Economics*, 87(4), 1077–1082.

Kuosmanen, T. and Kortelainen, M. (2005) Measuring eco-efficiency of production with data envelopment analysis. *Journal of Industrial Ecology*, 9, 59-72.

Kuznets, S. (1955), Economic growth and income inequality. *American Economic Review*, 45, 1–28.

Lakhan, C. (2016) The relationship between municipal waste diversion incentivizationand recycling system performance. *Resources, Conservation and Recycling*, 106, 68–77.

Laner, D., Crest, M., Sharff, H., Morris, J.W.F. & Barlaz, M.A. (2012) A review of approaches for the long-term management of municipal solid waste landfills. *Waste Management*, 32(3), 498–512.

Lansink, A.O. and Bezlepkin, I. (2003) The effect of heating technologies on CO_2 and energy efficiency of Dutch greenhouse firms. *Journal of Environmental Management*, 68, 73–82.

Laso, J., Hoehn, D., Margallo, M., García-Herrero, I., Batlle-Bayer, L., Bala, A., Fullana-i-Palmer, P., Vázquez-Rowe, I., Irabien, A. and Aldaco, R. (2018) Assessing Energy and Environmental Efficiency of the Spanish Agri-Food System Using the LCA/DEA Methodology. *Energies*, 11, 3395.

Lee, B.L., Wilson, C., Pasurka, Jr., Carl, A., Fujii, H. and Managi, S. (2017) Sources of airline productivity from carbon emissions: An analysis of operational performance under good and bad outputs. *Journal of Productivity Analysis,* 47(3), 223-246.

Lee, D. (2017) Overcoming the culture of waste. MIT Sloane Experts. Available at. [Accessed: 10 October 2018]

Lee, J.-D., Park, J.-B. and Kim, T.-Y. (2002) Estimation of the shadow prices of pollutants with production/environment inefficiency taken into account: a nonparametric directional distance function approach. *Journal of Environmental Management*, 64, 365–375.

Leigh, R. (2004) Economic growth as environmental policy? Reconsidering the Environmental Kuznets Curve. *Journal of Public Policy*, 24, 27-48.

Leppänen, J.M., Haahla, A.E., Lensu, A.M. and Kuitunen, M.T. (2012) Parent-Child Similarity in Environmental Attitudes: A Pairwise Comparison. *The Journal of Environmental Education*, 43(3), 162-176.

Levin, A., Lin, C. and Chu, J. (2002) Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Economics*, 108, 1–24.

Lewis, R.D. (1990) The Lewis Model. Cross Culture.

Lim, J. (1997) Economic Growth and Environment: Some Empirical Evidences from South Korea. School of Economics, University of New South Wales.

Lin, R. and Chen, Z. (2017) A directional distance based super-efficiency DEA model handling negative data. *Journal of the Operational Research Society*, 68 (11), p. 1312–1322.

Lins, M.P.E., Gomes, E.G., Soares de Mello, J.C.C.B. and Soares de Mello, A.J.R. (2003) Olympic ranking based on a zero sum gains DEA model. *European Journal of Operational Research*, 148, 312–322.

Lovell, C.A.K., Pastor, J.T. and Turner, J.A. (1995) Measuring macroeconomic performance in the OECD: A comparison of European and non-European countries. *European Journal of Operational Research*, 87, 507–518.

Lopez R. (1994) The environment as a factor of production: the effects of economic growth and trade liberalization. *Journal of Environmental Economics and Management*, 27, 163-184.

Lozano, S. and Gutiérrez, E. (2008) Non-parametric frontier approach to modelling the relationships among population, GDP, energy consumption and CO_2 emissions. *Ecological Economics*, 66(4), 687–699.

Lozano, S., Iribarren, D., Moreira, M.T. and Feijoo, G. (2009) The link between operational efficiency and environmental impacts: A joint application of Life Cycle Assessment and Data Envelopment Analysis. *Science of the Total Environment*, 407, 1744-1754.

Lozano, S., Gutiérrez, E. and Moreno, P. (2013) Network DEA approach to airports performance assessment considering undesirable outputs. *Applied Mathematical Modelling*, 37, 1665–1676.

Lu, W.M. and Lo, S.F. (2007) A closer look at the economic-environmental disparities for regional development in China. *European Journal of Operational Research*, 183, 882–894.

Magutu O.P., Mbeche M.I., Nyamwange O.S., Mwove M. and Ndubai E.R. (2010) Formulation and Implementation of Operation Strategies Used in Solid Waste Management: Case Study of City Council of Nairobi. Journal of African Research in Business and Technology, 2010.

Magutu O.P. and Onsongo, C.O. (2011) Operationalising Municipal Solid Waste Management, Integrated Waste Management - Volume II. Mr. Sunil Kumar (Ed.), InTech.

Mahlberg, B. and Sahoo, B.K. (2011) Radial and non-radial decompositions of Luenberger productivity indicator with an illustrative application. *International Journal of Production Economics*, 131, 721–726.

Malinauskaite, J., Jouhara, H., Czajczyńska, D., Stanchev, P., Katsou, E., Rostkowski, P., Thorne, R.J., Colón, J., Ponsá, S., Al-Mansour, F. Anguilano, L. Krzyżyńska, R., López, I.C., Vlasopoulos, A. and Spencer, N. (2017) Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. *Energy*, 141, 2013-2044.

Mandal, S.K. and Madheswaran, S. (2010) Environmental efficiency of the Indian cement industry: an interstate analysis. *Energy Policy*, 38, 1108-1118.

Mandl, U., Dierx, A. and Ilzkovitz, F. (2008) The effectiveness and efficiency of public spending (No. 301). *Directorate General Economic and Monetary Affairs (DG ECFIN),* European Commission.

Mardani, A., Zavadskas, E.K., Streimikiene, D., Jusoh, A. and Khoshnoudi, M. (2017) A comprehensive review of data envelopment analysis (DEA) approach in energy efficiency. *Renewable and Sustainable Energy Reviews*, 70, 1298–1322.

Marques, R.C. and Simões, P. (2009) Incentive regulation and performance measurement of the Portuguese solid waste management services. *Waste Management and Research,* 27, 188–196.

Maschio, G., Koufopanos, C. and Lucches, A. (1992) Pyrolysis, a Promising Route for Biomass Utilization. *Bioresource Technology*, 42, 219-231.

Mazzanti, M., (2008) Is waste generation de-linking from economic growth? Empirical evidence for Europe. *Applied Economics Letters* 15, 287–291.

Mazzanti, M. and Zoboli, R. (2005a) Waste generation, waste disposal and policy effectiveness: Evidence on decoupling from the European Union. *Resources, Conservation and Recycling*, 52, 1221–1234.

Mazzanti, M. and Zoboli, R. (2005b) Delinking and environmental Kuznets curves for waste indicators in Europe. *Environmental Sciences,* 2(4), 409–425.

Mazzanti, M. and Zoboli, R. (2008) Waste generation, waste disposal and policy effectiveness. Evidence on decoupling from the European Union. *Resources, Conservation and Recycling* 52, 1221–1234.

Mazzanti, M. and Zoboli, R. (2009) Municipal waste Kuznets curves: evidence on socio-economic drivers and policy effectiveness from the EU. *Environmental and Resource Economics*, 44, 203-230.

Mazzanti, M., Montini, A. and Zoboli, R. (2005) Municipal Waste Production, Economic Drivers, and 'New' Waste Policies: EKC Evidence from Italian Regional and Provincial Panel Data. CCMP – Climate Change Modelling and Policy.

Mazzanti, M., Montini, A. and Zoboli, R. (2009a). Municipal waste generation and the EKC hypothesis new evidence exploiting province-based panel data. *Applied Economics Letters*, 16, 719-725.

Mazzanti, M., Montini, A. and Zoboli, R. (2009b). Waste And Environmental Policy. London, New York: Routledge.

McBean, E.A., Rosso, E. & Rovers, F.A. (2005). Improvement in financing for sustainability in solid waste management. *Journal of Resources, Conservation and Recycling,* 43(4), 391–401.

McConnell K.E. (1997) Income and demand for environmental quality. *Environment and Development Economics,* 2, 383-399.

Metin, E., Erzturk, A. & Neyim, C. (2003) Solid waste management practices and review of recovery and recycling operations in Turkey. *Waste Management*, 23(5), 425–432.

Milbrandt, A., Seiple, T., Heimiller, D., Skaggs, R. and Coleman, A. (2018) Wet waste-to-energy resources in the United States. *Resources, Conservation and Recycling*, 137, 32-47.

Miranda, M.L. and Hale, B. (1997) Waste not, want not: the private and social costs of waste-to-energy production. *Energy Policy*, 25(6), 587-600.

Miranda, M.L. and Hale, B. (2005) Paradise recovered: energy production and waste management in island environments. *Energy Policy*, 33(13), 1691-1702.

Mohd, S.A., Khan, N., Ramli, R and Azizul Baten, M.D. (2015) Enhanced DEA model with undesirable output and interval data for rice growing farmers performance assessment. AIP Conference Proceedings 1691, 030016.

Moore, A., Nolan, J. and Segal, G. F. (2005) Putting out the trash measuring municipal service efficiency in US cities. *Urban Affairs Review*, 41(2), 237–259.

Mukherjee, K. (2008) Energy use efficiency in US manufacturing: a nonparametric analysis. *Energy Economics*, 30, 76–96.

Mukherjee, K. (2010) Measuring energy efficiency in the context of an emerging economy: the case of Indian manufacturing. *European Journal of Operational Research*, 201, 933–941.

Municipal Waste Europe (2017) Summary of the current EU legislation. Available at. [Accessed: 10 January 2017]

Murray, A., Skene, K. & Haynes, K. (2015) The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, 1-12.

Murtough, G., Appels, D., Matysek, A. and Lovell, C.A.K. (2002) Why greenhouse gas emissions matter when estimating productivity growth: An application to Australian electricity generation. Proceedings of the 2nd World Congress of Environmental and Resource Economists, Monterey, California.

Næss-Schmidt, H.S. and Jensen, L. (2015) Environmental policy analysis – Dealing with economic distortions. *TemaNord*, 576, Nordic Council of Ministers.

Nau, R. (2018) Notes on linear regression analysis. Available at. [Accessed: 20 August 2019]

Neyman, J. and Scott, E.L. (1948) Consistent estimates based on partially consistent observations. *Econometrica*, 16, 1–32.

Nicolaisen, J., Dean, A. and Hoeller, P. (1991) Economics and the Environment: A Survey of Issues and Policy Options. OECD Economic Studies No. 16.

Ng, S.I., Lee, J.A. and Soutar, G.N. (2006) Are Hofstede's and Schwartz's value frameworks congruent?. *International Marketing Review*, 24(2), 164-180.

Ogwueleka, T.C. (2013) Survey of household waste composition and quantities in Abuja, Nigeria. *Resource Conservation and Recycling*, 77, 52–60.

Ohnishi, S., Fujii, M., Ohata, M., Rokuta, I. and Fujita, T. (2018) Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city. *Resources, Conservation and Recycling,* 128, 394-405.

Ojeda-Benitez, S., de Vega, C.A. & Ramirez-Barreto, M.E. (2003) Characterization and quantification of household solid wastes in a Mexican city. *Resource Conservation and Recycling,* 39(3), 211–222.

Oosthuizen, J. (2018) Behavioural change a hurdle across industries. Engineering News. Available at. [Accessed: 10 September 2018]

Panayotou, T. (1997) Demystifying the environmental Kuznets curve: Turning a black box into a policy tool. *Environment and Development Economics*, 2(4), 465-484.

Parsons, T. (1951) The social system, Free Press, Glencoe, IL.

Pathomsiri, S., Haghani, A., Dresner, M. and Windle, R.J. (2008) Impact of undesirable outputs on the productivity of US airports. *Transportation Research*, Part E 44, 235–259.

Pedroni, P. (1999) Critical Values for Cointegration Tests in Heterogenous Panels with Multiple Regressors. *Oxford Bulletin of Economics and Statistics*, 61(4), 653-670.

Pedroni, P. (2000) Fully Modified OLS for Heterogeneous Cointegrated Panels. *Advances in Econometrics*, 15, 93-130.

Pedroni, P. (2004) Panel Cointegration; Asymptotic and Finite Sample Properties of Pooled Time Series Tests, With an Application to the PPP Hypothesis. *Econometric Theory*, 20, 597–625.

Peer, S., Goldman, D. and Yavetz, B. (2007) Environmental literacy in teacher training: Attitudes, knowledge, and environmental behaviour of beginning students. *Journal of Environmental Education*, 39(1), 45–59.

Pesaran, M.H. (2004) General Diagnostic Tests for Cross Section Dependance in Panels. IZA Discussion papers, No. 1240.

Petty, R.E. and Cacioppo, J.T. (1986) Communication and Persuasion: Central and Peripheral Routes to Attitude Change; Springer-Verlag: New York, NY, USA.

Picazo-Tadeo, A.J., Reig-Martinez, E. and Hernandez-Sancho, F. (2005) Directional distance function and environmental regulation. *Resource Energy Economics*, 27, 131–142.

Pires, A., Martinho, G. & Chang, N.B. (2011) Solid waste management in European countries: A review of systems analysis techniques. *Journal of Environmental Management,* 92(4), 1033-1050.

Pittman, R.W. (1981) Issues in pollution control: interplant cost differences and economies of scale. *Land Economics*, 57, 1–17.

Pittman, R. (1983) Multilateral productivity comparisons with undesirable outputs. *The Economic Journal*, 93, 883–891.

Plata-Diaz, A.M., Zafra-Gomez, J.L., Perez-Lopez, G. and Lopez-Hernandez, A.M. (2014) Alternative management structures for municipal waste collection services: The influence of economic and political factors. *Waste Management*, 34, 1967–1976.

Pongrácz, E. (2009) Through waste prevention towards corporate sustainability: analysis of the concept of waste and a review of attitudes towards waste prevention. *Sustainable Development*, 17(2), 92–101.

Qu, X., Li, Z., Xie, X., Sui, Y., Yang, L. & Chen, Y. (2009) Survey of composition and generation rate of household wastes in Beijing, China. *Waste Management,* 29(10), 2618–2674.

Podinovski, V.V. (2004) Bridging the Gap between the Constant and Variable Returns-to-Scale Models: Selective Proportionality in Data Envelopment Analysis. *The Journal of the Operational Research Society,* 55(3), 265-276.

Ramanathan, R. (2002) Combining indicators of energy consumption and CO 2 emissions: A crosscountry comparison. *International Journal of Global Energy Issues*, 17(3), 214–227.

Ramanathan, R. (2005) An analysis of energy consumption and carbon dioxide emissions in countries of the Middle East and North Africa. *Energy*, 30(15), 2831–2842.

Ramanathan, R. (2006) A multi-factor efficiency perspective to the relationships among world GDP, energy consumption and carbon dioxide emissions. *Technological Forecasting and Social Change*, 73, 483–494.

Ramli, N.A., Munisamy, S. and Arabi, B. (2013) Scale directional distance function and its application to the measurement of eco-efficiency in the manufacturing sector. *Annals of Operations Research*, 211(1), 381–398.

Reddy, G.T. (2015) Comparison and Correlation Coefficient between CRS and VRS models of OC Mines. *International Journal of Ethics in Engineering & Management Education*, 2(1), 2348–4748.

Redman, T.C. (2008) Data Driven: Profiting from Your Most Important Business Asset. Harvard Business Review Press.

Reinhard, S., Lovell, C.A.K. and Thijssen, G. (2000). Environmental efficiency with multiple environmentally detrimental variables estimated with SFA and DEA. *European Journal of Operational Research*, 121, 287–303.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Rentschler, J., Bleischwitz, R. and Flachenecker, F. (2018) On imperfect competition and market distortions: the causes of corporate under-investment in energy and material efficiency. *International Economics and Economic Policy*, 15, 159–183.

Reschovsky, J.D. and Stone, S.E. (1994) Market incentives to encourage household waste recycling: Paying for what you throw away. *Journal of Policy Analysis and Management*, 13(1), 120-139.

Rickinson, M. (2001) Learners and Learning in Environmental Education: A critical review of the evidence. *Environmental Education Research*, 7(3), 207-320.

Roberts, O.I. and Okereke, C.I. (2017) Cultural Beliefs on Waste and the need for Integration into Present Domestic Waste Management: Evidence from Selected Communities in Rivers State, Nigeria. *International Journal of Social Sciences and Management Research*, 3 (6).

Rogge, N. and De Jaeger, S. (2012) Evaluating the efficiency of municipalities in collecting and processing municipal solid waste: A shared input DEA-model. *Waste Management,* 32, 1968–1978.

Rogge, N. and De Jaeger, S. (2013) Measuring and explaining the cost efficiency of municipal solid waste collection and processing services. *Omega*, 41(4), 653–664.

Rovere, E.L.L., Soares, J.B., Oliveira, L.B. and Lauria, T. (2010) Sustainable expansion of electricity sector: sustainability indicators as an instrument to support decision making. *Renewable and Sustainable Energy Reviews*, 14(1), 422–429.

Ruggiero, J. (2011) Frontiers in Major League Baseball, Non parametric analysis of Performance using Data Envelopment Analysis. Springer.

Sachs, I. (2000) Understanding Development: People, Markets & the State in Mixed Economies. Oxford University Press: Oxford.

Sagiv, L. and Schwartz, S.H. (2007) Cultural values in organisations: insights for Europe. *European Journal of International Management*, 1(3), 176-190.

Sarc, R. and Lorber, K.E. (2013) Production, quality and quality assurance of Refuse Derived Fuels (RDFs). *Waste Management*, 33(9), 1825-1834.

Sarkis, J. (1999) Methodological framework for evaluating environmentally conscious manufacturing programs. *Computers & Industrial Engineering*, 36(4), 793–810.

Sarkis, J. and Cordeiro, J. J. (2001) An empirical evaluation of environmental efficiencies and firm performance: pollution prevention versus end-of-pipe practice. *European Journal of Operational Research*, 135(1), 102–113.

Sarkis, J. and Weinrach, J. (2001) Using data envelopment analysis to evaluate environmentally conscious waste treatment technology. *Journal of Cleaner Production*, 9(5), 417–427.

Schneider, D. (1972) What is kinship all about? In Kinship studies in the Morgan Memorial Year, P. Reinig (Ed.), Anthropological Society of Washington, Wash., DC.

Schwarz , G. (1978) Estimating the dimension of a model. *Annals of Statistics*, 6, 461–464.

Schwartz, S.H. (1977) Normative influence on altruism. In Advances in Experimental Social Psychology; Berkowitz, L., Ed.; Academic Press: New York, NY, USA, 221–279.

Schwartz, S.H. (1992) Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. In M. P. Zanna (Ed.), *Advances in Experimental Social Psychology*, 25, 1–66.

Schwartz, S. H. (1994) Beyond individualism/collectivism: New cultural dimensions of values. In U. Kim, H. C. Triandis, C. Kagitcibasi, S. C. Choi and G. Yoon (Eds.), Individualism and collectivism: Theory, methods, and applications (85–119). Thousand Oaks: Sage Publications.

Schwartz, S.H. (1999) Cultural value differences: some implications for work. *Applied Psychology: An International Review*, 48, 23–47.

Scheel, H. (2001) Undesirable outputs in efficiency valuations. *European Journal of Operational Research*, 132(2), 400–410.

Seiford, L.M., Thrall, R.M. (1990) Recent developments in DEA: The mathematical programming approach to frontier analysis*. Journal of Econometrics,* 46, 7–38.

Seiford, L.M., Zhu, J. (2002) Modeling undesirable factors in efficiency evaluation. *European Journal of Operational Research*, 142, 16-20.

Seiford, L.M., Zhu, J. (2005) A response to comments on modeling undesirable factors in efficiency evaluation. *European Journal of Operational Research*, 161, 579-581.

Serra, T., Chambers, R.G. and Oude Lansink, A. (2014) Measuring technical and environmental efficiency in a state contingent technology. *European Journal of Operational Research*, 236(2), 706-717.

Shackleton, V. J. and Ali, A. H. (1990) Work-related values of managers: A test of the Hofstede model. *Journal of Cross-cultural Psychology*, 21(1), 109-118.

Shafik, N. (1994) Economic development and environmental quality: an econometric analysis. *Oxford Economic papers*, 46, 757-773.

Shafik, N. and Bandyopadhyay, S. (1992) Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence. Background Paper for the World Development Report 1992, The World Bank, Washington DC.

Sharma, M. and McBean, E. (2007) A methodology for solid waste characterization based on diminishing marginal returns. *Waste Management,* 27(3), 337–344.

Sherman, H.D. and Zhu, J. (2006) Chapter 2: Data Envelopment Analysis explained. In: *Service Productivity Management, Improving Service Performance using Data Envelopment Analysis (DEA)*, Springer.

Silva Portela, M.C.A., Thanassoulis, E. and Simpson, G. (2004) Negative data in DEA: a directional distance approach applied to bank branches. *Journal of the Operational Research Society*, 55, 1111–1121.

Simar, L. and Wilson, P.W. (1998). Sensitivity analysis of efficiency scores: how to bootstrap in non parametric frontier models. *Management Science*, 44, 49-61.

Simar, L. and Wilson, P.W. (2000). A general methodology for bootstrapping in nonparametric frontier models. *Journal of Applied Statistics*, 27, 779 -802.

Simar, L. and Wilson, P.W. (2002). Non parametric tests of return to scale. *European Journal of Operational Research*, 139, 115-132.

Simões, P., De Witte, K. and Marques, R.C. (2010) Regulatory structures and operational environment in the Portuguese waste sector. *Waste Management*, 30, 1130–1137.

Simões, P., De Witte, K. and Marques, R.C. (2010) Regulatory structures and operational environment in the Portuguese waste sector. *Waste Management*, 30, 1130–1137.

Simões, P. and Marques, R.C. (2011) How does the operational environment affect utility performance? A parametric study on the waste sector. *Resources, Conservation and Recycling*, 55, 695–702.

Sjöström, M., Östblom, G. (2010) Decoupling waste generation from economic growth- A CGE analysis of the Swedish case. *Ecological Economics* 69, 1545-1552.

Skevas, T., Lansink, A.O. and Stefanou, S.E. (2012) Measuring technical efficiency in the presence of pesticide spillovers and production uncertainty: The case of dutch arable farms. *European Journal of Operational Research*, 223(2), 550-559.

Skevas, T., Stefanou, S. E. and Lansink, A.O. (2014) Pesticide use, environmental spillovers and efficiency: A DEA risk adjusted efficiency approach applied to Dutch arable farming. *European Journal of Operational Research*, 237, 658-664.

Smith P.B., Peterson, M.F. and Schwartz, S.H. (2002) Cultural values, sources of guidance, and their relevance to managerial behaviour: a 47-nation study. *Journal of Cross-cultural Psychology*, 33(2), 188-208.

Sondergaard, M. (1994) Hofstede's consequences: A study of reviews, citations and replications. *Organization Studies*, 15(3), 447-456.

Song, M., An, Q., Zhang, W., Wanga, Z. and Wub, J. (2012) Environmental efficiency evaluation based on data envelopment analysis: A review. *Renewable and Sustainable Energy Reviews*, 16, 4465–4469.

Song, M., Peng, J., Wang, J. and Dong, L. (2018) Better resource management: An improved resource and environmental efficiency evaluation approach that considers undesirable outputs. *Resources, Conservation and Recycling*, 128, 197-205.

Song, T., Zheng, T. and Tong, L. (2008) An empirical test of the environmental Kuznets curve in China: A panel cointegration approach. *China Economic Review*, 19, 381-392.

Song, M., Yang, L., Wu, J. and Lv, D. (2013) Energy saving in China: Analysis on the energy efficiency via bootstrap-DEA approach. *Energy Policy*, 57, 1-6.

Soukopová, J. (2011) Metody ekonomické analýzy a jejich využití pro hodnocení výdajů na ochranu životního prostředí. In Soukopová, J. (Ed.), Výdaje obcí na ochranu životního prostředí a jejich efektivnost, Brno, Czech Republic, *Littera*, 103-142.

Špaček, D., Malý, I. and Bakoš, E. (2011) Efektivnost veřejných výdajů na ochranu životního prostředí. In Soukopová, J. (Ed.), Výdaje obcí na ochranu životního prostředí a jejich efektivnost. Brno, Czech Republic, *Littera*, 85-102.

Stapp, W.B. (1974) Historical setting of environmental education, in J. A. Swan & W. B. Stapp (Eds) Environmental education: strategies toward a more livable future, New York, Sage.

Steenkamp, J.B.E.M. (2001) The role of national culture in international marketing research. *International Marketing Review*, 18(1), 30–44.

Stephan, F.F. (1934) Sampling Errors and Interpretations of Social Data Ordered in Time and Space. *Journal of the American Statistical Association*, 29, 165-166.

Sterbenz, C. (2014) This Chart Explains Every Culture In The World. Business Insider, Available at: http://www.businessinsider.com/inglehart-welzel-culture-map-2014-7 [Accessed: 10 November 2017].

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY
H.F.R.I. Hellenic Foundation for Research & Innovation

Stern, D.I. (2003) The Environmental Kuznets Curve. *International Society for Ecological Economics*. Internet Encyclopaedia of Ecological Economics.

Stern, D.I., Common, M.S. and Barbier, E.B. (1996) Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development. *World Development*, 24, 1151-1160.

Stevenson, R.B. (2007) Schooling and environmental education: contradictions in purpose and practice. *Environmental Education Research*, 13(2), 139-153.

Stokey N.L. (1998) Are there limits to growth? *International Economic Review*, 39, 1-31.

Sueyoshi, T. and Goto, M. (2012a) Weak and strong disposability vs. natural and managerial disposability in DEA environmental assessment: Comparison between Japanese electric power industry and manufacturing industries. *Energy Economics*, 686-699.

Sueyoshi, T. and Goto, M. (2012b) Returns to scale and damages to scale on U.S. fossil fuel power plants: Radial and non-radial approaches for DEA environmental assessment. *Energy Economics*, 34, 2240-2259.

Sueyoshi, T. and Goto, M. (2014) DEA radial measurement for environmental assessment: A comparative study between Japanese chemical and pharmaceutical firms. *Applied Energy*, 115, 502–513.

Sueyoshi, T., Yuana, Y. and Goto, M. (2017) A literature study for DEA applied to energy and environment. *Energy Economics*, 62, 104–124.

Sujauddin, M., Huda, S. M. S., Rafiqul, A. T. M. & Hoque, R. (2008) Household solid waste characteristics and management in Chittagong, Bangladesh. *Waste Management,* 28(9), 1688–1695.

Sukholthaman, P., Chanvarasuth, P. and Sharp, A. (2017) Analysis of waste generation variables and people's attitudes towards waste management system: a case of Bangkok, Thailand. *Journal of Material Cycles and Waste Management*, 19(2), 645–656.

Sun, S. (2002) Measuring the relative efficiency of police precincts using data envelopment analysis. *Socio-Economic Planning Sciences*, 36, 51–71.

Suthar, S. & Singh, P. (2015) Household solid waste generation and composition in different family size and socio-economic groups: A case study. *Sustainable Cities and Society,* 14, 56-63.

Suzuki, S. and Nijkamp, P. (2016) An evaluation of energy-environment-economic efficiency for EU, APEC and ASEAN countries: Design of a Target-Oriented DFM model with fixed factors in Data Envelopment Analysis. *Energy Policy*, 88, 100-112.

Tamaki, T., Nakamura, H., Fujii, H. and Managi, S. (2019) Efficiency and emissions from urban transport: Application to world city-level public transportation. *Economic Analysis and Policy*, 61, 55-63.

Thanassoulis, E. (1995) Assessing police forces in England and Wales using data envelopment analysis. *European Journal of Operational Research*, 87, 641–657.

Thanh, N. P., Matsui, Y. & Fujiwara, T. (2010) Household solid waste generation and characteristic in a Mekong Delta city, Vietnam. *Journal of Environmental Management*, 91(11), 2307–2321.

The Trustees of Princeton University (2007) Interpreting Regression Output. Available at. [Accessed: 15 August 2019]

Tone, K. (2001) A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research*, 130(3), 498–509.

Tone, K. (2004) Dealing with undesirable outputs in DEA: a Slacks-Based Measure (SBM) approach. *Presentation at NAPWIII*. Toronto.

Torres-Reyna, O. (2007) Panel Data Analysis Fixed and Random Effects using Stata (v. 4.2). Princeton University.

Triandis, H. C. (1982) Culture's consequences. *Human Organization*, 41(1), 86-90.

Trindade, A.B., Palacio, J.C.E., Gonzales, A.M., Orozco, D.J.R, Lora, E.E.S., Renó, M.L.G. and del Olmo, O.A. (2018) Advanced exergy analysis and environmental assesment of the steam cycle of an incineration system of municipal solid waste with energy recovery. *Energy Conversion and Management*, 157, 194-214.

Trompenaars, F. and Hampden-Turner, C. (1997) Riding the Waves of Culture: Understanding Cultural Diversity in Business. 2nd Edition, McGraw Hill, New York.

Trompenaars, F. and Hampden-Turner, C. (2010) The Seven Dimensions of Culture: A Definition.

Troschinetz, A.M. and Mihelcic, J.R. (2009) Sustainable recycling of municipal solid waste in developing countries. *Waste Management*, 29(2), 915-923.

Tsai, P.F. and Mar Molinero, C. (2002) A Variable Returns to Scale Data Envelopment Analysis Model for the Joint Determination of Efficiencies with an Example of the UK Health Service. *European Journal of Operational Research*, 141(1), 21-38.

Tsai, T.-h. (2008) The impact of social capital on regional waste recycling. *Sustainable Development*, 16(1), 44-55.

Tyteca, D. (1996) On the measurement of the environmental performance of firms: a literature review and productive efficiency perspective. *Journal of Environmental Management*, 46(3), 281–308.

Tyteca, D., (1997) Linear programming models for the measurement of environmental performance of firms – Concepts and empirical results. *Journal of Productivity Analysis*, 8, 183–197.

Usui, T. and Takeuchi, K. (2014) Evaluating Unit-Based Pricing of Residential Solid Waste: A Panel Data Analysis. *Environmental and Resource Economics*, 58, 245–271.

Vergara, S.E. and Tchobanoglous, G. (2012) Municipal Solid Waste and the Environment: A Global Perspective. *Annual Review of Environment and Resources*, 37, 277–309.

Vlontzos, G., Niavis, S. and Pardalos, P. (2017) Testing for Environmental Kuznets Curve in the EU Agricultural Sector through an Eco-(in)Efficiency Index. *Energies*, 10 (12), 1-15.

Vyas, G.S., Jha, K.N. (2017) Benchmarking green building attributes to achieve cost effectiveness using a data envelopment analysis. *Sustainable Cities and Society*, 28, 127-134.

Watkins, E. (2015). A case study on illegal localised pollution incidents in the EU. A study compiled as part of the EFFACE project. London: IEEP.

Westerlund, J. (2007) Testing for Error Correction in Panel Data. *Oxford Bulletin of Economics and Statistics*, 69(6), 709-748.

Wheeler, K. (1975) The genesis of environmental education, in: G. C. Martin & K. Wheeler (Eds). Insights into environmental education (Edinburgh, Oliver Boyd).

Wilson, D.C. (2007) Development drivers for waste management. *Waste Management Research*, 25(3), 198–207.

Wu, J., Zhang, W., Xu, J. and Che, Y. (2015) A quantitative analysis of municipal solid waste disposal charges in China. *Environmental Monitoring and Assessment*, 187(60), 1-10.

Wu, Y., Xi, X., Tang, X., Luo, D., Gu, B., Lam, S.K., Vitousek, P.M. and Chen, D. (2018) Policy distortions, farm size, and the overuse of agricultural chemicals in China. *Proceedings of the National Academy of Sciences*, 115(27), 7010-7015.

Yaisawarng, S. and Klein, J.D. (1994) The effects of sulfur dioxide controls on productivity change in the US electric power industry. *The Review of Economics and Statistics*, 76, 447–460.

Yamaguchi, R. and Managi, S. (2017) New financing for sustainable development: the case for NNP- or inclusive wealth-linked bonds. *Journal of Environment and Development*, 26(2), 214–239.

Yang, C.C., Hsiao, C. K. and Yu, M.M. (2008) Technical efficiency and impact of environmental regulations in farrow to finish swine production in Taiwan. *Agricultural Economics*, 39(1), 51-61.

Yang, H.L. and Michael, P. (2010) The necessity of distinguishing weak and strong disposability among undesirable outputs in DEA: environmental performance of Chinese coal-fired power plants. *Energy Policy,* 38(8), 4440–4444.

GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

H.F.R.I. Hellenic Foundation for Research & Innovation

Yang, H. and Pollitt, M. (2009) Incorporating both undesirable outputs and uncontrollable variables into DEA: The performance of Chinese coal-fired power plants. *European Journal of Operational Research*, 197, 1095–1105.

Yang, H. and Pollitt, M. (2010) The necessity of distinguishing weak and strong disposability among undesirable outputs in DEA: Environmental performance of Chinese coal-fired power plants. *Energy Policy*, 38, 4440–4444.

Yang, K.-S. (1988) Will societal modernization eventually eliminate cross-cultural psychological differences? In M. H. Bond (Ed.). The cross-cultural challenge to social psychology (67-85). Newbury Park, CA: Sage Publications.

Yoo, B. and Donthu, N. (1998) Validating Hofstede's Five-dimensional Measure of Culture at the Individual Level, American Marketing Association (Boston, MA: Summer Marketing Educators' Conference).

Yu, M.M. (2004) Measuring physical efficiency of domestic airports in Taiwan with undesirable outputs and environmental factors. *Journal of Air Transport Management*, 10, 295–303.

Yüksel, H. (2012) Evaluating the Success of Waste Collection Programs of Municipalities with Data Envelopment Analysis. *International Journal of Environmental Protection*, 2(5), 6-8.

UNESCO/UNU-IHDP and UNEP (2014) Inclusive Wealth Report 2014: Measuring Progress Toward Sustainability, Cambridge University Press: Cambridge.

UNEP (2011) Tourism: Investing in Energy and Resource Efficiency. United Nations Environment Programme. Available at. [Accessed: 5 April 2017]

UNEP (2015) Global Waste Management Outlook. United Nations Environment Programme. Available at. [Accessed: 20 March 2017]

Wang, K., Huang, W., Wu, J. and Liu, Y.N. (2014) Efficiency measure of the Chinese commercial banking system using an additive two-stage DEA. *Omega*, 44, 5–20.

Wang, K., Yuc, S. and Zhang, W. (2013) China's regional energy and environmental efficiency: A DEA window analysis based dynamic evaluation. *Mathematical and Computer Modelling*, 58, 1117–1127.

Wang, Q., Zhou, P. and Zhou, D. (2012) Efficiency measurement with carbon dioxide emissions: The case of China. *Applied Energy*, 90(1), 161–166.

Williams, R.M. (1970) American Society: A Sociological Interpretation. 3rd ed., Knopf, New York.

WMR (2009) Incineration. Waste Management Resources. Available at. [Accessed: 10 January 2017]

World Bank (1999) What a Waste: Solid Waste Management in Asia, Urban Development Sector Unit, East Asia and Pacific Region, Available at. [Accessed: 20 April 2017]

World Energy Council (2016) World Energy Resources. Waste to Energy 2016.

Worthington, A. C. and Dollery, B. E. (2001) Measuring efficiency in local government: An analysis of New South Wales municipalities' domestic waste management function. *Policy Studies Journal*, 29(2), 232–249.

WRAP (2016) Anaerobic digestion. The Waste and Resources Action Programme. Available at. [Accessed: 5 February 2017]

Wursthorn, S., Poganietz, W.R. and Schebek, L. (2011) Economic-environmental monitoring indicators for European countries: a disaggregated sector-based approach for monitoring eco-efficiency. *Ecological Economics*, 70, 487–496.

WVS (2008) Cultural Map. Available at. [Accessed: 20 September 2018]

WVS (2015) World Value Surveys. WVS Wave 7, Available at. [Accessed: 20 September 2018]

WWF (2012) Denmark waste to energy. Available at. [Accessed: 20 January 2017]

Yeh, T.L, Chen, T.Y. and Lai, P.Y. (2010) A comparative study of energy utilization efficiency between Taiwan and China. *Energy Policy*, 38, 2386–2394.

Zaim, O. (2004) Measuring environmental performance of state manufacturing through changes in pollution intensities: A DEA framework. *Ecological Economics*, 48(1), 37–47.

Zanella, A. (2014) Assessment of performance in the presence of undesirable outputs: the promotion of livability and sustainable development of cities and countries using Data Envelopment Analysis. PhD Thesis.

Zelezny, L.C., Chua, P. and Aldrich, C. (2000) Elaborating on gender differences in environmentalism. *Journal of Social Issues*, 56, 443–457.

Zhang, B., Bi, J., Fan, Z., Yuan, Z. and Ge, J. (2008) Eco-efficiency analysis of industrial system in China: A data envelopment analysis approach. *Ecological Economics*, 68, 306 – 316.

Zhang, N., Zhou, P. and Choi, Y. (2013) Energy efficiency, CO_2 emission performance and technology gaps in fossil fuel electricity generation in Korea: a meta-frontier non-radial directional distance function analysis. *Energy Policy,* 56, 653–662.

Zhen-shan, L., Lei, Y., Xiao-Yan, Q. & Yu-mei, S. (2009) Municipal solid waste management in Beijing City. *Waste Management*, 29(9), 2618–2624.

Zhou, P., Ang, B.W. and Poh, K.L. (2008) Measuring environmental performance under different environmental DEA technologies. *Energy Economics*, 30(1), 1–14.

Zhou, P., Ang, B.W. and Wang, H. (2012) Energy and CO_2 emission performance in electricity generation: a non-radial directional distance function approach*. European Journal of Operational Research*, 221, 625–635.

Zhou, P., Poh, K.L. and Ang, B.W. (2007) A non-radial DEA approach to measuring environmental performance. *European Journal of Operational Research*, 178, 1–9.

Zhou, Y., Ma, M., Kong, F., Wang, K. and Bi, J. (2018) Capturing the co-benefits of energy efficiency in China — A perspective from the water-energy nexus. *Resources, Conservation and Recycling*, 132, 93-101.

Zofio, J.L. and Prieto, A.M. (2001) Environmental efficiency and regulatory standards: The case of CO_2 emissions from OECD industries. *Resource and Energy Economics*, 23, 63–83.