HAROKOPIO UNIVERSITY

SCHOOL OF ENVIRONMENT, GEOGRAPHY & APPLIED ECONOMICS

DEPARTMENT OF GEOGRAPHY

The era of Anthropocene. Evidence from global energy and material flows in human-natural systems.

Bachelor's Thesis

Kalimeris I. Panagiotis

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ΧΑΡΟΚΟΠΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ

ΣΧΟΛΗ ΠΕΡΙΒΑΛΛΟΝΤΟΣ, ΓΕΩΓΡΑΦΙΑΣ ΚΑΙ ΕΦΑΡΜΟΣΜΕΝΩΝ ΟΙΚΟΝΟΜΙΚΩΝ

ΤΜΗΜΑ ΓΕΩΓΡΑΦΙΑΣ

Η Εποχή της Ανθρωπόκαινου. Παγκόσμιες Ροές Ενέργειας και Ύλης στα Ανθρώπινα και Φυσικά Συστήματα

Διπλωματική Εργασία

Καλημέρης Ι. Παναγιώτης

Αθήνα, 2022

ΧΑΡΟΚΟΠΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ

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ΤΜΗΜΑ ΓΕΩΓΡΑΦΙΑΣ

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δηλώνω υπεύθυνα ότι:

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Στον Δημήτρη και τη Χρυσούλα,

με την ευχή να καταφέρουμε να τους κληροδοτήσουμε

έναν καλύτερο κόσμο.

“Sic transit gloria mundi”[1]

“τὰ πάντα ῥεῖ καὶ οὐδὲν μένει”

Ηράκλειτος

Picture: *Filmmakers record an atomic bomb blast in Nevada in 1957. Credit: Galerie Bilderwelt/Getty (Source: Subramanian, 2019 – Available at: https://www.nature.com/articles/d41586-019-01641-5)*

[1] *«Έτσι παρέρχεται η δόξα του κόσμου»: Φράση του τελετουργικού ενθρόνισης ενός νέου Πάπα, κατά την περίοδο 1409-1963*

ΕΥΧΑΡΙΣΤΙΕΣ

Αν θα μπορούσα να ξεχωρίσω δύο λόγους για τους οποίους αποφάσισα να εισαχθώ με κατατακτήριες εξετάσεις στο τμήμα Γεωγραφίας, τότε σίγουρα αυτοί θα ήταν οι εξής: Πρώτον, η αγάπη για το φυσικό περιβάλλον, την ορειβασία, τη γεωμορφολογία των ελληνικών βουνών και τους χάρτες και, δεύτερον, η πνευματική ένδεια και η έλλειψη δημιουργικής εκτόνωσης της ακαδημαϊκής «*διαστροφής*», στη φύση της καθημερινής μου εργασιακής απασχόλησης, η οποία εν τέλει αντισταθμίστηκε με τη συνειδητή επιλογή παρακολούθησης ενός προπτυχιακού προγράμματος.

Γηράσκω αεί διδασκόμενος, το λοιπόν, και η προσπάθεια να παραμείνεις *tabula rasa*, καταστέλλοντας το *εγώ* και τον όποιο *ναρκισσισμό* φέρει στις αποσκευές της η «*αυθεντία*» σου, μπροστά στη γοητεία ενός νέου επιστημονικού πεδίου που ανοίγεται μπροστά σου, εξελίχθηκε εν τέλει σε ένα συναρπαστικό γνωστικό ταξίδι.

Θέλω να ευχαριστήσω προσωπικά τον Καθηγητή κ. Καρύμπαλη Ε., για την ουσιαστική υποστήριξη και αμέριστη συμπαράσταση, κατά τη διάρκεια εκπόνησης της παρούσας Διπλωματικής εργασίας. Επίσης, θα ήθελα να ευχαριστήσω τους συναδέλφους μου και τους προϊσταμένους μου στη Διεύθυνση Υλικού και Προμηθειών της ΔΕΗ Α.Ε. για την κατανόησή τους όλα αυτά τα χρόνια, ειδικότερα κατά τη διάρκεια των εξεταστικών περιόδων.

Τέλος, θα ήθελα να ευχαριστήσω την Μαργαρίτα για την υποστήριξη και την κατανόηση που έδειξε όλον αυτόν τον καιρό που προσπαθούσα να ολοκληρώσω τις σπουδές μου, παράλληλα με τις λοιπές εργασιακές, επιστημονικές και διδακτικές μου υποχρεώσεις, και, φυσικά, τη «*γλυκιά συμμορία*» για τη γλυκιά αναστάτωση της καθημερινής μας συγκατοίκησης!

Αθήνα, 28.02.2022

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Ελληνική Περίληψη (Greek extended abstract)

Σύμφωνα με τη Διεθνή Επιτροπή Στρωματογραφίας (ICS) που αποτελεί όργανο της Διεθνούς Ένωσης Γεωλογικών Επιστημών (IUGS), επισήμως, βρισκόμαστε στην γεωλογική εποχή/σειρά της Ολόκαινου, η οποία ξεκίνησε πριν περίπου 11.700 χρόνια, με το τέλος της τελευταίας παγετώδους περιόδου και της προηγούμενης Πλειστόκαινου εποχής, αμφότερες μέρη της ευρύτερης Τεταρτογενής περιόδου. Ο προσδιορισμός των λιθολογικών ενοτήτων και η τεκμηρίωση των στρωματογραφικών ορίων που προσδιορίζουν τα χρονολογικά όρια των γεωλογικών διαβαθμίσεων αποτελεί μια μακροχρόνια διαδικασία η οποία υπόκειται στον σχολαστικό έλεγχο διεθνών επιτροπών και γεωλογικών επιστημονικών κοινοτήτων. Επομένως, γίνεται αντιληπτό ότι η οποιαδήποτε τροποποίηση της επίσημης χρονολογικής κλίμακας της ιστορίας της Γης θα πρέπει να ιδωθεί υπό το φως των διαδικασιών της ICS και, εν τέλει, της IUGS. Παρόλα αυτά, είναι ευρέως αποδεκτό σήμερα σε διεπιστημονικό επίπεδο, ότι η ανθρώπινη δραστηριότητα προξενεί διαχρονικά σημαντικές πιέσεις στο γήινο φυσικό περιβάλλον, οι οποίες έχουν επιφέρει σημαντικές αρνητικές επιπτώσεις σε όλα τα επίπεδα της βιόσφαιρας, από την ατμόσφαιρα, το έδαφος και τους ωκεανούς, έως το παγκόσμιο κλίμα. Στο πλαίσιο αυτό, όλο και περισσότεροι επιστήμονες συγκλίνουν στην άποψη ότι η ανθρωπότητα, ως σύνολο, λειτουργεί πλέον σαν μια ισχυρή γεωλογική δύναμη, συγκρινόμενη με τις δυνάμεις της φύσης, η οποία μετασχηματίζει δραστικά και πολυεπίπεδα τον πλανήτη Γη, με αποτέλεσμα την επιτακτική ανάγκη για την αναγνώριση της εποχής μας ως μια νέα διακριτή γεωλογική εποχή, αυτήν της Ανθρωπόκαινου[2].

Η σύγχρονη πρόταση για την υιοθέτηση μιας νέας γεω-ιστορικής περιόδου, υπό το νεολογισμό «*Ανθρωπόκαινος*», βασίζεται εν πολλοίς στην προσπάθεια (από το 2000) του Ολλανδού Χημικού της Ατμόσφαιρας Πάουλ Γιόζεφ Κρέτσεν, βραβευθείς με Νόμπελ Χημείας το 1995, και του Αμερικανού Παλαιό-Βιολόγου Γιουτζίν Στόερμερ,

[2] Επιλέγεται, χάριν ευκολίας και συνέπειας, το θηλυκό γένος της Εποχής της Ανθρωπόκαινου. Πάραυτα, αξίζει να επισημανθεί ότι στη σχετική βιβλιογραφία στα ελληνικά γίνεται χρήση και του αρσενικού γένους (ο Ανθρωπόκαινος).

να αναδειχθεί η επίδραση του ανθρώπου επάνω στη βιόσφαιρα, ως ένας ιδιόμορφος αλλά καθοριστικός «γεωλογικός» παράγοντας. Μια ενδελεχής ιστορική αναδρομή της σχετικής βιβλιογραφίας, που επιχειρείται στο ***1ο Κεφάλαιο*** της παρούσας εργασίας, αποκαλύπτει ότι η βασική ιδέα της Ανθρωπόκαινου εποχής έρχεται από πολύ μακριά. Ήδη, από το 1775, ο Γάλλος φυσιοδίφης Λεκρέκ ντε Μπουφόν αναγνωρίζει τη δύναμη που έχει η ανθρωπότητα να δρα ως γεωλογικός παράγοντας, μιλώντας για την «*Ανθρώπινη γεωλογική εποχή*». Το 1854, ο Ουαλός θεολόγος και γεωλόγος Τόμας Τζένκιν φαίνεται να είναι ο πρώτος που δημοσιεύει την ιδέα μιας ανθρώπινης εποχής στη γεωλογική κλίμακα, υπό τον όρο «*Ανθρωποζωϊκός*», ενώ βασιζόμενος στην ίδια λογική, ο Ιταλός γεωλόγος και θεολόγος Αντόνιο Στοππάνι προτείνει το 1873 τον ίδιο όρο στην Ιταλική Γλώσσα. Ενδιαφέρον παρουσιάζει επίσης το γεγονός ότι αρκετοί Σοβιετικοί επιστήμονες χρησιμοποιούν ήδη από τις αρχές του εικοστού αιώνα, παρεμφερείς έννοιες, όπως η «νοόσφαιρα».

Η δημοτικότητα που απέκτησε ο νεολογισμός της Ανθρωπόκαινου εποχής σε πλήθος επιστημονικών πεδίων, αποτυπώνεται στη δημιουργία τριών διεθνών επιστημονικών περιοδικών με κριτές, με κύριο στόχο την έρευνα επάνω στη νέα γεω-ιστορική εποχή. Ασκώντας επίσης σημαντική επιρροή στον τύπο και άρα στην κοινή γνώμη, επηρεάζοντας την τέχνη μέσα από την παραγωγή σχετικών ντοκιμαντέρ, αλλά και υπερεθνικούς οργανισμούς οι οποίοι υιοθετούν τον όρο σε επιτροπές τους, όλη αυτή η συνεπακόλουθη «πίεση» για την επίσημη αναγνώρισή της νέας εποχής από τις γεωλογικές επιστήμες, οδήγησε την ICS το 2008 σε μια ιστορική απόφαση: στη δημιουργία της ομάδας εργασίας Ανθρωπόκαινου (AWG) επιφορτισμένης με την επιστημονική τεκμηρίωση του στρωματογραφικού αποτυπώματος της υπό εξέταση εποχής. Η τελευταία ψηφοφορία της AWG έλαβε χώρα τον Μάιο του 2019 και με ποσοστό 88% υπέρ, κατατέθηκε η νέα επεξεργασμένη πρόταση της ομάδας στην ICS για έγκριση. Δεδομένης όμως της κατάστασης που έχει δημιουργήσει η πανδημία σε παγκόσμιο επίπεδο, δεν αναμένεται κάποια ουσιαστική πρόοδο πριν το τέλος 2022.

Όπως συνεπάγεται από τα παραπάνω, το πρώτο βήμα προσδιορισμού της προτεινόμενης γεω-χρονικής περιόδου είναι ο αυστηρός καθορισμός ενός ευρέως αποδεκτού ορόσημου - διαχωρισμού της από την Ολόκαινο εποχή και, ως εκ τούτου, του επίσημου σημείου έναρξης αυτής. Προς αυτή την κατεύθυνση, τις τελευταίες δύο δεκαετίες έχει δημοσιευτεί ένας μεγάλος όγκος ερευνητικών προτάσεων. Η βιβλιογραφική ανασκόπηση για τα προτεινόμενα ορόσημα έναρξης της Ανθρωπόκαινου εποχής παρουσιάζεται στο ***2ο Κεφάλαιο*** της εργασίας και χωρίζεται σε δύο μεγάλες κατηγορίες:

- Τη ***Μάκρο-Ανθρωπόκαινη*** θεώρηση: Στην ενότητα αυτή παρουσιάζονται όλες εκείνες οι προτάσεις οι οποίες θέτουν ουσιαστικά υπό αμφισβήτηση σχεδόν ολόκληρη την Ολόκαινο εποχή, πηγαίνοντας ακόμα περισσότερο πίσω, καλύπτοντας και μέρος της Πλειστόκαινου. Προτάσεις που βασίζονται στην:
    - Ανακάλυψη και συστηματική χρήση της φωτιάς,
    - Έμμεση συνεισφορά του ανθρώπου σε μεγάλες μαζικές εξαφανίσεις ειδών,
    - Αποκαλούμενη Αγροτική Επανάσταση, που οδήγησε σε μεγάλης κλίμακας ανθρωπογενείς αλλαγές στις χρήσεις γης, εξημέρωση αλλά και εξαφάνιση ειδών του φυτικού και του ζωικού βασιλείου, αλλά και θεμελίωσε την ζωή των ανθρώπων σε κοινότητες και πόλεις, ευνοώντας έτσι τη σταδιακή αύξηση του ανθρώπινου πληθυσμού,
    - Ανίχνευση ανθρωπογενών επιδράσεων στην Πεδόσφαιρα, στη διαδικασία δημιουργίας του εδάφους, της χέρσου, του στρώματος που βρίσκεται μεταξύ της Ατμόσφαιρας και της Λιθόσφαιρας.

- Τη **Μίκρο-Ανθρωπόκαινη** θεώρηση: Στη δεύτερη κατηγορία παρουσιάζονται οι προτάσεις οι οποίες τοποθετούν την πιθανή έναρξη της Ανθρωπόκαινου εποχής σε πολύ πιο πρόσφατες χρονικές περιόδους, όπως:
    - Την περίοδο των μεγάλων ανακαλύψεων και της αποικιοκρατίας, μετά το 1500, με εστίαση κυρίως στο έτος 1610,
    - Την περίοδο της αποκαλούμενης «*Βιομηχανικής Επανάστασης*», στην Μεγάλη Βρετανία αρχικά, την περίοδο 1750-1800,
    - Μετά το τέλος τους Δευτέρου Παγκοσμίου πολέμου, το 1945, και ειδικότερα την εποχή της αποκαλούμενης «*Μεγάλης Επιτάχυνσης»,* μετά το 1950,

- Τις πρώτες πυρηνικές δοκιμές, ειδικότερα μετά το 1963, όπου εμφανίζονται νέες μορφές ύλης που δεν υπήρξαν ποτέ στο παρελθόν, όπως ορισμένα ραδιοϊσότοπα, και το πλαστικό.

Στο ***3ο Κεφάλαιο***, υιοθετώντας ουσιαστικά το έτος 1950, την αρχή της περιόδου της «*Μεγάλης Επιτάχυνσης»* - που αποτελεί και την επικρατέστερη πρόταση της ομάδας εργασίας της Ανθρωπόκαινου (AWG), επιχειρείται η ανίχνευση της Ανθρωπόκαινου μέσα από την εκτενή παρουσίαση των σημαντικότερων ανθρωπογενών τάσεων και των επιπτώσεων αυτών στο πλανητικό σύστημα. Ειδικότερα, το κεφάλαιο αυτό χωρίζεται σε δύο ενότητες:

- Την ενότητα των *Οικονομικό-Κοινωνικών ροών* που αποτελούν το «**Ανθρωπογενές Σύστημα**», το άμεσο αποτύπωμα της Ανθρωπόκαινου εποχής. Στην ενότητα αυτή επιχειρείται η ποσοτική ανάλυση των ανθρωπογενών ροών, μέσα από τη χρήση εκτενών βάσεων δεδομένων σε μορφή χρονοσειρών, για έξι (6) βασικές μεταβλητές:
    - Τη διαχρονική αύξηση του ανθρώπινου πληθυσμού, που αποτελεί ουσιαστικά την θεμελιώδη κινητήρια δύναμη που πυροδοτεί την αύξηση των υπολοίπων υπό εξέταση μεταβλητών.
    - Το Ακαθάριστο Εγχώριο Προϊόν (ΑΕΠ), ως μεταβλητή που αποτυπώνει την οικονομική μεγέθυνση.
    - Την παγκόσμια κατανάλωση ενεργειακών φυσικών πόρων, ειδικότερα των ορυκτών καυσίμων, ως η κινητήρια δύναμη της παγκόσμιας οικονομίας.
    - Την παγκόσμια κατανάλωση υλικών φυσικών πόρων ως η υλική υπόσταση του συνόλου των ανθρώπινων αγαθών, κατασκευών και υποδομών.
    - Την παγκόσμια παραγωγή τροφής και την εμπορική διακίνηση αυτής, μέσω των δικτύων του παγκόσμιου εμπορίου.
    - Την παραγωγή πλαστικού, ως ένα ενδεικτικό τεχνητό υλικό το οποίο, ως ανθεκτικό στην αποσύνθεση απόρριμμα, αναμένεται να αποτελέσει βασικό συστατικό στοιχείο της δημιουργίας ανιχνεύσιμου ανθρωπογενούς στρωματογραφικού στρώματος.

- Την ενότητα που παρουσιάζει το «**Φυσικό Σύστημα**», όπου επιχειρείται να αποδοθεί συνοπτικά η πιθανή αρνητική-αποσταθεροποιητική επίδραση των ανθρωπογενών ροών επάνω σε έξι (6) θεμελιώδεις φυσικές λειτουργίες του και, ως εκ τούτου, μπορούν να αποτελέσουν επιπρόσθετα επιχειρήματα που ενισχύουν την πρόταση της υιοθέτησης της Ανθρωπόκαινου εποχής, πέρα από τα στενά πλαίσια της στρωματογραφικής ανάλυσης:
    - Η ανθρωπογενής έκλυση διοξειδίου του άνθρακα στην ατμόσφαιρα και η συνεπακόλουθη ανθρωπογενής κλιματική αλλαγή.
    - Η διατάραξη της στοιβάδας του Όζοντος.
    - Η απώλεια της παγκόσμιας βιοποικιλότητας και οι ενδείξεις για την, πιθανώς εν εξελίξει, 6η μαζική εξαφάνιση ειδών, η οποία για πρώτη φορά στην ιστορία συνεπικουρείται κυρίαρχα από ανθρωπογενείς παράγοντες.
    - Η ευστατική αύξηση της στάθμης της θάλασσας λόγω διαφόρων παραγόντων, όπως αύξηση της θερμοκρασίας των ωκεανών, το λιώσιμο του παγετώδους καλύμματος, τις λοιπές κλιματικές συνιστώσες κ.α.
    - Η Οξίνιση των ωκεανών, ως αποτέλεσμα απορρόφησης του διοξειδίου του άνθρακα από την ατμόσφαιρα, που οδηγεί σε μείωση του pH του θαλασσινού νερού.
    - Οι Μεταβολές στα μεγάλα θαλάσσια ρεύματα και στην ωκεάνια κυκλοφορία που ενδέχεται να μεταβάλουν το κλίμα σε διάφορες γεωγραφικές ζώνες, με απροσδιόριστες συνέπειες.

Τέλος, ως ανακεφαλαίωση των παραπάνω, παρουσιάζεται ένα από τα πλέον καινοτόμα μεθοδολογικά πλαίσια ποσοτικοποίησης των ανθρωπογενών επιπτώσεων επάνω στα φυσικά οικοσυστήματα, τα Πλανητικά Όρια (Planetary Boundaries), καθώς και η επικαιροποίησή τους, που δημοσιεύτηκε στις αρχές του 2022.

Το **4ο Κεφάλαιο** αποτελεί μια μελέτη περίπτωσης που εξειδικεύει την παρούσα ανάλυση, στην προσπάθεια πιθανής ανίχνευσης της Ανθρωπόκαινου υπόθεσης, σε τρείς (3) συγκεκριμένες κατηγορίες υδατικών οικοσυστημάτων:

- Τα Δελταϊκά συστήματα των μεγαλύτερων ποταμών του πλανήτη
- Τα Λιμναία υδατικά συστήματα
- Τα Παράκτια οικοσυστήματα

Εν κατακλείδι, το **5º Κεφάλαιο** ολοκληρώνει την παρούσα εργασία επιχειρώντας να σταχυοθετήσει τα σημαντικότερα ευρήματα και συμπεράσματα αυτής. Συμπερασματικά, μολονότι ο δρόμος προς την επίσημη αναγνώριση μιας νέας γεωλογικής εποχής προβλέπεται επίπονος, αφού καλείται να περάσει μέσα από τις Συμπληγάδες διεθνών επιστημονικών επιτροπών, αυστηρής κριτικής, και μακροχρόνιων διαβουλεύσεων, εντούτοις, η ευρεία χρήση του όρου «Ανθρωπόκαινος», από ένα πλήθος επιστημονικών κλάδων και διεθνών οργανισμών, έχοντας συνεισφέρει πολλαπλά ως πεδίο διεπιστημονικής έρευνας, αποτελεί ασφαλώς μια έμμεση αναγνώριση. Υπό το πρίσμα αυτό, μια επίσημη αναγνώριση του όρου ίσως θα μπορούσε να επιτελέσει έναν πολλαπλό στόχο, σε μια εποχή όξυνσης των περιβαλλοντικών πιέσεων, αλλά και ταυτόχρονης συνειδητοποίησης του ρόλου που ενέχει ο ανθρώπινος παράγοντας πίσω από αυτές, όπως η δημιουργία ενός πολιτικού-επιστημονικού προτάγματος που θα ασκήσει μεγαλύτερη πίεση στα κέντρα αποφάσεων, στη διεθνή κοινότητα, στους υπερεθνικούς οργανισμούς αλλά και στην ενίσχυση της επίγνωσης της κοινής γνώμης για το ηθικό βάρος των πράξεων της.

Εξάλλου, όπως και η παρούσα διπλωματική εργασία αναδεικνύει, ίσως η επίσημη αναγνώριση της εποχής μας ως την εποχή της Ανθρωπόκαινου, ξεφεύγει από τα καλά ορισμένα – αλλά στενά – πλαίσια της επιστήμης της στρωματογραφίας και της γεωλογίας και απαιτεί μια ολιστική θεώρηση της αλληλοεπίδρασης μεταξύ του τεχνητού και του φυσικού περιβάλλοντος, εντός της Βιόσφαιρας. Η ραγδαία επιδείνωση μιας σειράς καθοριστικών παραμέτρων, κρίσιμων για τη βιολογική-οικολογική ισορροπία-διατήρηση της ζωής, καθώς και η παραβίαση κρίσιμων βιοφυσικών ορίων της πλανητικής λειτουργίας, όπως αυτά αποτυπώνονται μέσα από τους δείκτες της μεθοδολογίας των Πλανητικών Ορίων (Planetary Boundaries), επιτάσσουν μια περισσότερο ολοκληρωμένη διεπιστημονική προσέγγιση.

Αναμφίβολα, μέσα από μια ολιστική διεπιστημονική προσέγγιση, διαφαίνεται το ειδικό βάρος των μέγα-ροών που έχει κατορθώσει να δημιουργήσει το ανθρώπινο γένος, καθώς και οι σχετικές αρνητικές εξωτερικότητες-πιέσεις που αυτές δημιουργούν στο φυσικό σύστημα, κάνοντας όλο και περισσότερο επιτακτική την ανάγκη για τον μετριασμό των επιπτώσεων, εντός των πλανητικών ορίων, προκειμένου να τιθασεύσουμε και να ισορροπήσουμε την ορμή της Ανθρωπόκαινου εποχής, ανεξάρτητα από την επίσημη ή μη αναγνώριση αυτής.

Λέξεις κλειδιά:

Ανθρωπόκαινος, Στρωματογραφία, Πλανητικά όρια, Φυσικοί Πόροι, Βιωσιμότητα

English Abstract

Established by the endeavours of Paul Crutzen and Eugene Stoermer in early 2000s, to underline the consequences of anthropogenic impacts on the biosphere, the neologism of «*Anthropocene*» is currently predominant in the interdisciplinary scientific research of numerous scientific fields, others than geology. Despite the popularity of the term and the fact that three peer-reviewed scientific journals are dedicated on the Anthropocene, its formal recognition, as an official geological epoch/series or stage/age, remains yet an open debate within the realms of stratigraphy and geology (as we formally live in the Holocene epoch). Towards this direction, the International Commission on Stratigraphy (ICS), formal body of the International Union of Geological Sciences (IUGS), established in 2008 the Anthropocene Working Group (AWG), in charge of preparing the formal proposal of the nominated new epoch/series for acceptance (or not).

The present thesis initially reviews the relevant literature, from the early attempts in 18th century to the seminal study of Crutzen and Stoermer in 2000, concluding with the status quo of the ongoing AWG's endeavour towards formal recognition. Furthermore, in the 2nd Chapter, the literature review deals with the proposed initial point of the new epoch, the so-called "*golden spike*", divided in two categories: the Macro-Anthropocene hypothesis, dealing with long-term perspectives, such as the use of fire by humans and the so-called Agricultural Revolution; and, the Micro-Anthropocene hypothesis, investigating short-term perspectives, such as the era of colonization, the Industrial Revolution and the so-called period of the "*Great Acceleration*".

The 3rd Chapter aspires to present direct and indirect evidence of the Anthropocene hypothesis in both human and natural systems. To do so, the analysis is distinguished in two sections: the first section estimates the socio-economic trends revealing the magnitude of Anthropocene, by selected mainstream variables, such as the population and GDP growth, natural resources consumption, food production and plastic materials; the second section presents selected critical variables revealing the anthropogenic impacts in the natural systems, such as carbon dioxide emissions,

atmospheric ozone layer depletion, ocean's acidification and eustatic sea level rise, biodiversity loss and oceanic circulation disturbances.

The 4th Chapter provides three selected case-studies of Anthropocene's impacts on: the deltaic systems of many of the greatest river basins of the world; the inland lakes; and, the coastal zone. Finally, the 5th Chapter presents the conclusions and a brief discussion of the main findings and suggestions of the present thesis. In a nutshell, albeit a formal recognition of the Anthropocene epoch is still pending, an informal yet persistent global recognition is ongoing. Considering the dynamics, the term already incorporates, someone might anticipate that a formal recognition could further trigger more action towards building strongest sustainability perspective. Moreover, it should be outlined that the formal recognition might exceeds the narrow perspective of the stratigraphy framework, as the multidimensional anthropogenic impacts on the natural system call for brave interdisciplinary justification and acceptance. Be that as it may, perhaps the formal engagement of an Anthropocene's era, in the global political and decision makers' arena, could boost the mutual understanding and opinion convergence concerning more immediate, decisive, and solid action towards confronting humanity's major environmental challenges.

Keywords: Anthropocene; Stratigraphy; Geology; GSSP; Climate Change; Material Flow Analysis (MFA); Great Acceleration; Planetary Boundaries

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Vocabulary - Glossary

AMOC: Atlantic Meridional Overturning Circulation

AWG: Anthropocene Working Group

BP: Before Present

CFCs: Chlorofluorocarbons

DMC: Domestic Material Consumption

EJ: Exajoule

EoL: End of Life

ESLR: Eustatic Sea Level Rise

GDP: Gross Domestic Product

GSSA: Global Standard Stratigraphic Age

GSSP: Global Boundary Stratotype Section and Points

ICC: International Chronostratigraphic Chart

ICS: International Commission on Stratigraphy

IGBP: International Geosphere-Biosphere Programme

IUGS: International Union of Geological Sciences

MFA: Material Flow Analysis or Accounting

Mt: Million tons

PETM: Paleocene-Eocene Thermal Maximum

ppm: parts per million

PTB: Physical Trade Balance

SLR: Sea Level Rise

TPES: Total Primary Energy Supply

1. An Introduction to Anthropocene. A historical review

1.1. Introduction

It is said that, sometimes the best way to introduce a new idea to the reader is by using the actual words of the initial inspirator. According to a recent obituary published in the prestigious "*The Economist*" journal (The Economist, 2021), dedicated to the founder of the whole idea of introducing a new geological epoch, during 2000: "*Paul Crutzen was in Cuernavaca at a scientific meeting devoted to understanding the operation of Earth as a system. The term "Holocene" was used again and again in the sessions, but Crutzen found himself increasingly irritated by hearing the term used to encompass both the world of today and the world of the first farmers, a world of a few million people and of a few billion, a world of fires in hearths and a world of oilfields. He could not accept the view that humans just happened to occupy their period in the same way that dinosaurs happened to occupy the Jurassic and trilobites the Ordovician. And so, he interrupted (ibid):*

- *"Stop saying the Holocene! We're not in the Holocene anymore!"*
- *"So where are we then Paul?" his colleagues asked. He cast around, hesitated, then decided:*
- *"The Anthropocene!"*."

We may not be able to verify the validity of the above dialogue; perhaps the capture of this moment remains just an imaginative way, an elegant fiction, of a journalist's effort to intricate the reader's imagination[3]. Yet, we can be sure that Crutzen's radical idea, which was indeed conceived during that period, was going to create hot debates in the realms of Geology and Stratigraphy, whilst at the same time, introduced a beloved buzzword for many other scientific fields.

Despite the lack of any official recognition yet, Anthropocene is a favourite term; an online research on 23rd October of 2021 for the neologism "Anthropocene", by using

[3] To be honest, a more extensive research reveals that there is the confirmation of Will Steffen, who was present at that conference in Mexico, and thus he witnessed the above storytelling (Steffen, 2013)

the Google Scholar tool[4], returned almost 250,000 results. These numbers reveal the undoubtful broad use of the concept over the last 20 years, in various multidisciplinary scientific fields, from environmental and ecological economics, to sustainability, ecology, climatology and geomorphology, to mention but a few. Evidently, according to Malhi (2017), since the introduction of the term by Crutzen and Stoermer (2000), there was a remarkable increment in the use of the term (see Fig. 1).

The present thesis aspires to review the literature, from the early formulation of the Anthropocene hypothesis and the ongoing geological debate running silently behind its formal use, to the broad utilization of the term by various scientific fields, from ecology, environmental and natural sciences, to economics.

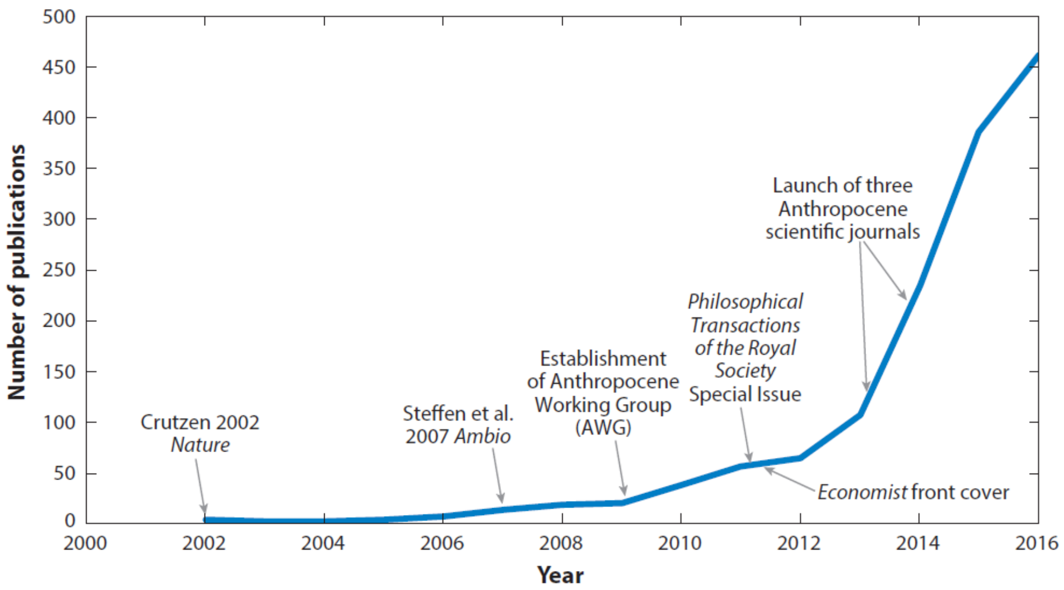

Figure 1. *Depiction of the evolution of publications in scientific journals per year, on the topic "Anthropocene", from Crutzen's seminal study in 2002, as an initial point, up until 2016 (Source: Malhi, 2017 – p.80).*

The first chapter of the present thesis is dedicated to the definition of the Anthropocene hypothesis. Furthermore, the chapter deals with the official endeavour of the so-called Anthropocene Working Group (AWG), established by the International Commission on Stratigraphy (ICS), towards a formal recognition of Anthropocene, as

[4] Available at: https://scholar.google.com/

a new geological epoch/series, or not. It worth mentioned here that, since the official recognition of Anthropocene is still pending, we adopt hereinafter the Anthropocene concept as the "*Anthropocene hypothesis*".

1.2. Early contributions, etymology, and the emerging hypothesis of a new geological epoch

The etymology of the neologism "Anthropocene" is derived by the unity of two Greek words: "Anthropos" (*Άνθρωπος*), meaning "human"; and "kainos" (*καινός*), meaning "new" and/or "recent". The use of the "– cene" ending is common in geological time scaling. Before we continue the story of how P. Crutzen was inspired the geological era of mankind (Crutzen, 2002), it is vital to trace some early contributions towards this direction.

Trischler (2016) and Rudwick (2005) provide a very insightful historical review of how the concept of an age, characterized by long run human impacts on the Earth system, has early attracted the human thought. In 1775 French naturalist Georges-Louis Leclerc de Buffon, in his early attempt to describe earth's history, made the distinction between the "*original*" and the "*civilized by humans*" nature; In his own words (Buffon 1778: 237[5]): ''*the entire face of the Earth bears the imprint of human powe*r''. Buffon described the human geological epoch as the seventh and the final one, paralleling in a way the biblical 7th day of creation (Rudwick, 2005). In 1854, Thomas Jenkyn, a Welsh geologist and theologist, seems to be the first who published the term "*Antropozoic*", to describe the idea of the human epoch in geological time scale (Rudwick, 2005). In his own words: "*All the recent rocks, called in our last lesson Post-Pleistocene, might have been called Anthropozoic, that is, human-life rocks*" (Jenkyn, 1854). In 1864 George Marsh described the transformative force of human beings on shaping the Earth's surface. In the same line, Reverend Samuel Haughton used the term "*Anthropozoic*" in his Manual of Geology, published in 1865. Similarly, the Italian priest and geologist Antonio Stoppani[6] proposed in 1873, nearly thirteen decades before

[5] Retrieved by Trischler (2016)

[6] More information on Stoppani's contribution may be found in Turpin and Federighi (2012).

Crutzen's conception of the Anthropocene, the term "*antropozoico*", arguing that the modern era was an age dominated by humankind. These early remarkable contributions are very little known and rarely cited by the relevant literature, although it is based on the very same foundations with Crutzen's much later idea (Turpin and Federighi, 2012). Furthermore, the Ukrainian geochemist Vladimir Vernadsky emphasized the role of humans as a "*significant geological force*" in his idea of Noosphere (thus, biosphere combined with human intelligence, in Greek «*νοόσφαιρα*») in 1913, while his teacher Russian geologist Alexei Pavlov spoke of an "*anthropogenic system or Anthropocene*" (Rudwick, 2005; Trischler, 2016). In 1915, the German scientist Ernst Fischer published an article under the title "*Der Mensch als geologischer Faktor*" (Fischer, 1915), which was translated in 1922 in English as: "*Man as a Geological Agent*".

Evidently, as we are moving forward in time from the initial point of the so-called Industrial Revolution, we identify numerous intellectuals anticipating, more or less, the main idea of the Anthropocene. The biologist Hubert Markl (re-) engaged the term "*Anthropozoikum*", back in the '80s, probably following Jenkyn's and Stoppani's early conceptions, to describe the present geological age. Remarkably, J.R. McNeill, Professor in the Department of History at the Georgetown University, provides in his seminal book "*Something new under the sun*" insightful thoughts on humans acting as geological agents, just before the first publication of the term "Anthropocene" (McNeill, 2000). McNeill suggests that humankind has become a significant geological agent, altering the Earth's surface biologically, chemically, and physically (ibid). According to Trischler (2016), even the limnologist Eugene F. Stoermer had already begun to use the term Anthropocene informally back in the '80s, long before his formal cooperation and co-authorship with Paul Crutzen.

Be that as it may, the initial point of the Anthropocene Hypothesis is the seminal article published in International Geosphere-Biosphere Programme's (IGBP) newsletter (No 41)[7] in page 17, of the Royal Swedish Academy of Sciences, a joint authorship of both Crutzen and Stoermer (2000). As being an exceptional Dutch atmospheric chemist, awarded in 1995 with the prestigious Nobel Prize in Chemistry, Paul Crutzen, through his lifelong research and discoveries of how atmospheric pollutants can destroy stratospheric ozone, which protects Earth from harmful ultraviolet radiation, had an increasing concern over the impacts of aggregate human activities on Earth's natural system. In that sense, the inception of the neologism "Anthropocene" (See the etymology above), was nothing less but an effort to firmly emphasize the anthropogenic causes of climate change. As many other scientists in the past, Crutzen realized that a powerful notion, with solid scientific basis, ought to be constructed and formally adopted in order to firmly display human power as a new geological era re-shaping the Earth's crust, climate, and hydro-geo-chemical cycles of the biosphere.

1.3. Towards the formal recognition; The establishment of AWG and an open debate

1.3.1. The formal case of Holocene

As being the official scientific body of the International Union of Geological Sciences (IUGS), the main purpose of the International Commission on Stratigraphy (ICS) is to define accurately and precisely the units (in particular, eonothems/eons; erathems/eras; systems/periods; series/epochs; and ages/stages) of the International Chronostratigraphic Chart (ICC) which defines the official geological timescale and, thus expressing the official/formal geological history of Earth. The ICS is divided in seventeen (17) sub-commissions, each one specialized in a specific geological period. By using the on-line interactive tool of ICS, we may reproduce the formally approved and internationally accepted present status of the ICC, in Figure 2. According to the formal geological time scale accounting, we are living in the Meghalayan age of the

[7] Available here:
http://www.igbp.net/download/18.316f18321323470177580001401/1376383088452/NL41.pdf
(Retrieved in 14.02.2022)

Holocene epoch, of the Quaternary period[8], of the Cenozoic era, of the Phanerozoic eon.

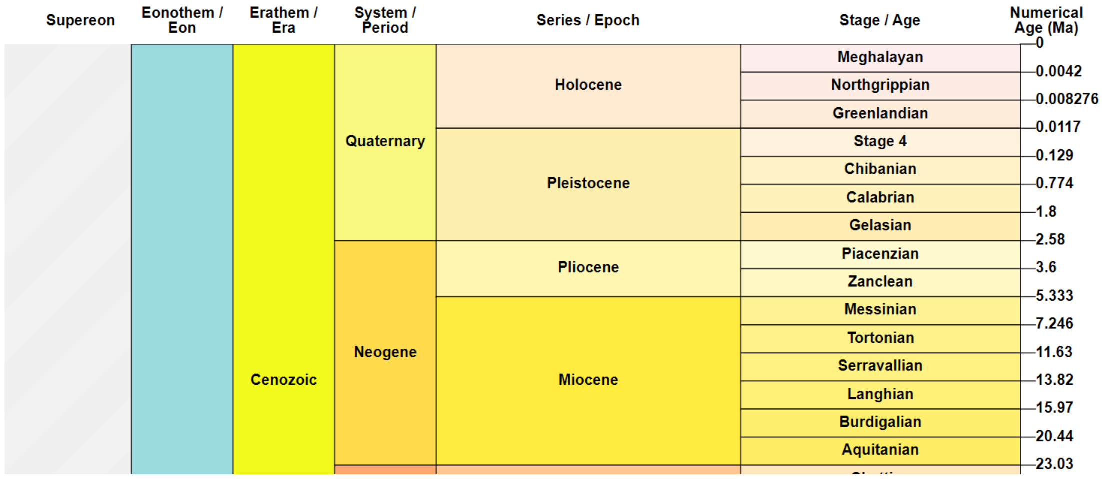

Figure 2. *Partially reproduced International Chronostratigraphic Chart (ICC) with no scaling, until Neogene period of the Cenozoic Era. (Source: https://stratigraphy.org/timescale/)*

The most critical tool for defining stratigraphic sections and boundaries of geological time scale is the Global Boundary Stratotype Section and Points (GSSPs) which are the reference points defining the lower of stratigraphic sections and the respective stage of geological time scale. Since 1977, the ICS has established very strict rules[9] that must be applied for a section to be adopted formally as an official GSSP. In line with these well documented and internationally adopted rules, it becomes clear that any effort of establishing a new GSSP ought to fulfil the standards set by ICS, otherwise it will not

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[8] Based on a common stratotype at Monte San Nicola, Sicily, Italy, dated circa 2.58 Ma (See, e.g. (Gibbard *et al.*, 2009).

[9] A geologic section ought to fulfill a set of criteria to be adapted as a GSSP by the ICS, such as:

- A GSSP must define the lower boundary of a geologic Stage.
- The lower boundary must be defined using a primary marker (usually first appearance datum of a fossil species).
  - There should also be secondary markers (other fossils, chemical, geomagnetic reversal).
  - The horizon in which the marker appears should have minerals that can be radiometrically dated.
  - The marker must have regional and global correlation in outcrops of the same age
  - The marker should be independent of facies.
- The outcrop must have an adequate thickness
- Sedimentation must be continuous without any changes in facies
- The outcrop should be unaffected by tectonic and sedimentary movements, and metamorphism
- The outcrop must be accessible to research and free to access.

Source: https://stratigraphy.org/gssps/ (Retrieved in 03.01.2022) be eligible for potential ICC amendments. According to the formal GSSP table, the status of the upper Meghalayan stage has been recently ratified, in 2018[10] (See Figure 3). Evidently, GSSPs are the accepted boundary markers and, thus, are known as the "*golden spikes*", among geologists (Lewis and Maslin, 2015).

SubSeries	Stage	Age (Ma)	GSSP Location	Latitude, Longitude	Boundary Level	Correlation Events	Status	Reference
Phanerozoic Eonothem								
Cenozoic Erathem								
Quaternary Period								
Holocene Series								
Upper	Meghalayan Stage	4,250 yr b2k (before 2000 CE)	Mawmluh Cave, Meghalaya, India	25°15'44"N; 91°42'54"E	depth 7.45 mm in the speleothem KM-A	Climatic - 4.2 ka event	Ratified 2018	*Episodes* 2018; 41: 213-223. (PDF)

Figure 3. *Partially reproduced Tables of Period's GSSPs for latest Upper Meghalayan stage (Source: https://stratigraphy.org/gssps/)*

Holocene[11] is the current geological series/epoch, starting with the ending of the last glacial period, around 11,700 years BP. Etymologically, the term is derived by the union of two Greek words (όλο + καινός = Ολόκαινος), which in English means the "*entirely/totally - new/recent*". The term is quite old, initially proposed around 1860 by the French geologist Paul Gervais, following the endeavor of Charles Lyell to describe the contemporary geological time, after the last glacial period, as the "*recent epoch*", around 1830 (Ibid). Apparently, questioning the well-documented and well-established Holocene epoch, within the realms of geological science, requires sound evidence and global GSSPs "golden spikes" that ought to be approved, among others, by the official bodies of ICS and IUGS.

1.3.2. The establishment of the Anthropocene Working Group (AWG)

Since the first use of the term by Stoermer back in the 1980s and the world-wide recognition received by Crutzen's efforts, together with Stoermer, in the 2000s, there

[10] For more see: https://stratigraphy.org/gssps/files/meghalayan.pdf (Retrieved in 03.01.2022)

[11] The GSSP boundary between the Pleistocene and Holocene is based on the NGRIP core (75.1°N, 42.32°W; see e.g.: Walker *et al.,* 2009)

has been an enormous production of publications and scientific debates, on a wide interdisciplinary basis, that will be further discussed later on. Probably, the publicity the debate received, as well as the widely adoption of the term by numerous scientific fields – other than geology – and the increasing criticism-pressure within the geological scientific community, led the ICS into a historical decision; to engage, within the "*Subcommission on Quaternary Stratigraphy*", a working group on the "*Anthropocene*", hereinafter known as the "*Anthropocene Working Group*" (AWG) (See the official log in Fig.4). AWG was established in 2009 and since then it has produced a remarkable body of relevant peer-reviewed publications and eleven (11) official annual newsletters from 2009 to 2020[12]. The coronavirus pandemic probably affected the preparation of the respective newsletter for 2021, which has yet to be published.

Figure 4. *The official logo of the Anthropocene Working Group – AWG of the Subcommission on Quaternary Stratigraphy of ICS (Source: http://quaternary.stratigraphy.org/working-groups/anthropocene/)*

[12] Annual Newsletters of AWG (period: 2009-2020) are available here (Retrieved in 04.01.2022):
- Newsletter No.1 2009
- Newsletter No.2 2010
- Newsletter No.3 2012
- Newsletter No.4 2013
- Newsletter No.5 2014
- Newsletter No.6 2015
- Newsletter No.7 2017
- Newsletter No.8 2018
- Newsletter No.9 2019
- Newsletter No.10 2020

AWG has performed a biding vote of all participant members in May 21st of 2019, in line with the guidance of ICS for at least 60% participation in voting, to confirm the acceptance of some major key points. The latest voting results announcement are published in the official webpage of AWG and are summarized as follows:

Number of total voting members: 34

Votes received: 33 (97%) – The 60% of the voting body is 21, thus the vast majority voted. Votes (88%) exceed the 60% supermajority limit set by ICS, of votes required to be agreed by the AWG as the official proposal of the group.

The relevant questions of the voting and the respective results are presented in the following Table 1:

Questions	Votes in favor	Votes against	Result
Should the Anthropocene be treated as a formal chrono-stratigraphic unit defined by a GSSP?	29 (88%)	4	Approved
Should the primary guide for the base of the Anthropocene be one of the stratigraphic signals around the mid-twentieth century of the Common Era?	29 (88%)	4	Approved

Table 1. *The two main questions of the 19th May of 2019 voting process of AWG's members and the respective results.*

According to the latest AWG newsletter of 2020, the future planning is to create a full dataset and extensive explanations per candidate GSSP case study, until the summer of 2022. This material will be used by the AWG voting membership on the preferred GSSP site or sites, and further propose possible auxiliary sites. The next AWG voting is anticipated to take place in late 2022 (October to November, the latest), in order to announce the voting outcome in December 2022. Then, in the mid-2023, there should be prepared the final summary of the results and the reasoning of the GSSP and auxiliary sites selection. The final proposal would be submitted, probably by the end of 2023 to the Subcommission on Quaternary Stratigraphy for debate and approval. Figure 5 describes the long distance that need to be covered until the final approval and the potential formal amendment of geological time scale.

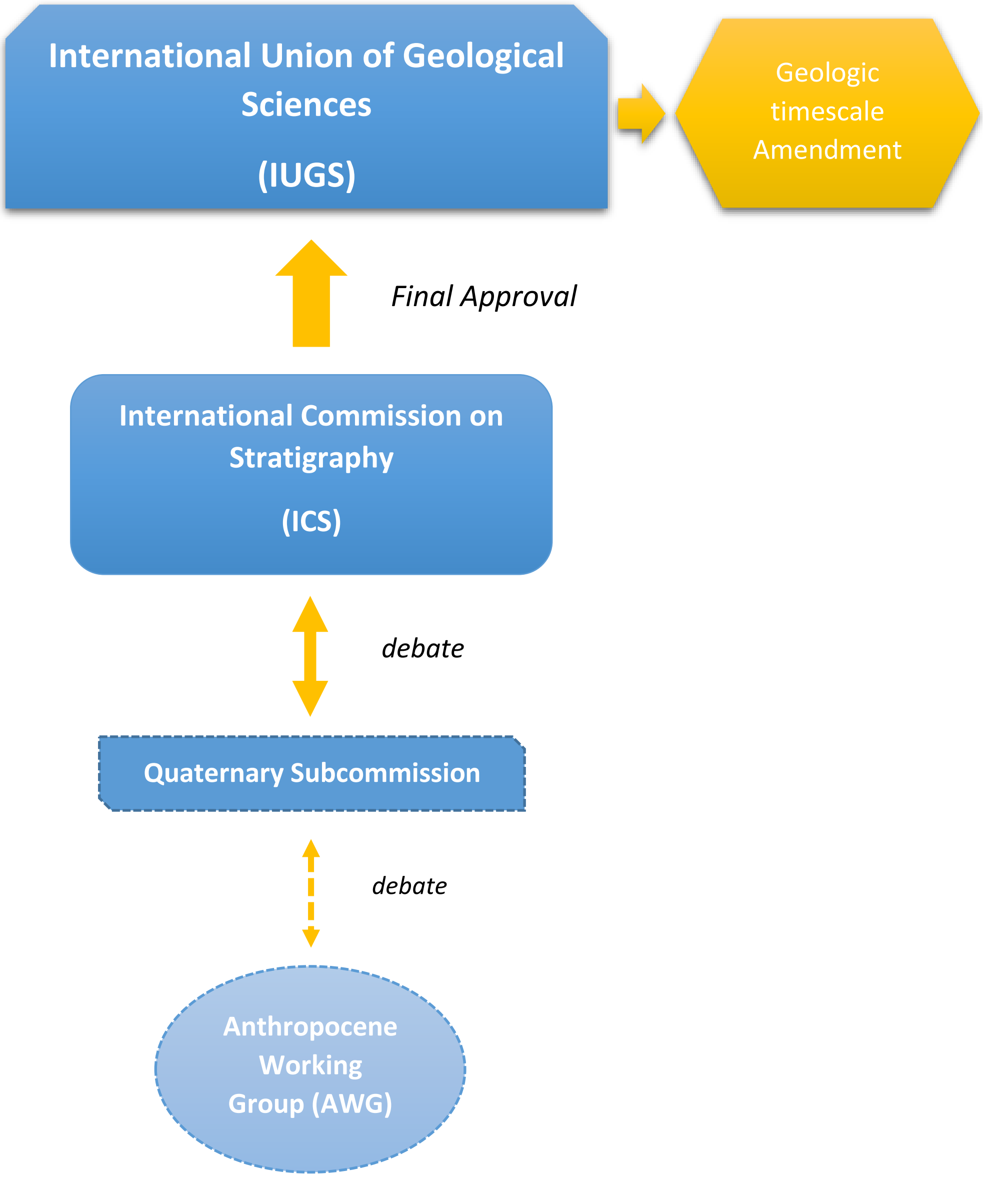


Figure 5. *Towards the procedure of formal recognition, AWG's proposal must be submitted for debate and approval to the quaternary subcommission, then in ICS for further debate and, if accepted, to IUGS for final debate and approval (or rejection).*

Through the years of AWG's contributions and research progress, there have been established various sub-groups explicitly investigating for evidence of the Anthropocene in specific fields and aspects, such as:

Lithostratigraphic signals:

- Direct signals: Investigating the so-called "Urban Stratum" of manmade infrastructure, mining, extracting, and building processes and materials.
- Indirect signals: changes in erosion and sedimentation due to land use changes, dam construction, chemical flows, etc., associated with urbanization and agriculture.
- Global dispersion of many "new minerals" including concrete, fly ash and plastics, and the numerous artificial fossils, known as "technofossils", produced from these and other (artificial or not) materials.

Biostratigraphic signals:

- Species extinction rates
- Habitat loss, predation, explosion of domestic animal populations and invasive species flows caused by these changes, or anthropogenic global commerce and globalization

Chemostratigraphic signals:

Changes to major natural cycles of carbon, nitrogen, phosphorus, metals, and radionuclides distributions.

Atmospheric Chemistry:

The human-induced increment in greenhouse gases, compared to the geological past, both in the Quaternary (at glacial phase terminations) and in earlier events such as the Palaeocene-Eocene Thermal Maximum, anthropogenic ozone layer depletion, and so on.

Sea level changes stratigraphy:

Environmental changes generated by chemo-bio stratigraphic changes, including global warming, sea-level rise, ocean acidification through the observed pH decrease, and the ongoing spread of oceanic "*dead zones*" through fishery depletion, coral reefs death, and so on.

The AWG recognizes that most of the above investigated changes will have long term impacts, for millennia or even longer, and are already affecting the natural trajectory of the Earth System, with potential permanent status.

The latest candidate GSSPs which are currently under investigation by the AWG, are presented in Figure 6 and, in more detail, in Table 2.

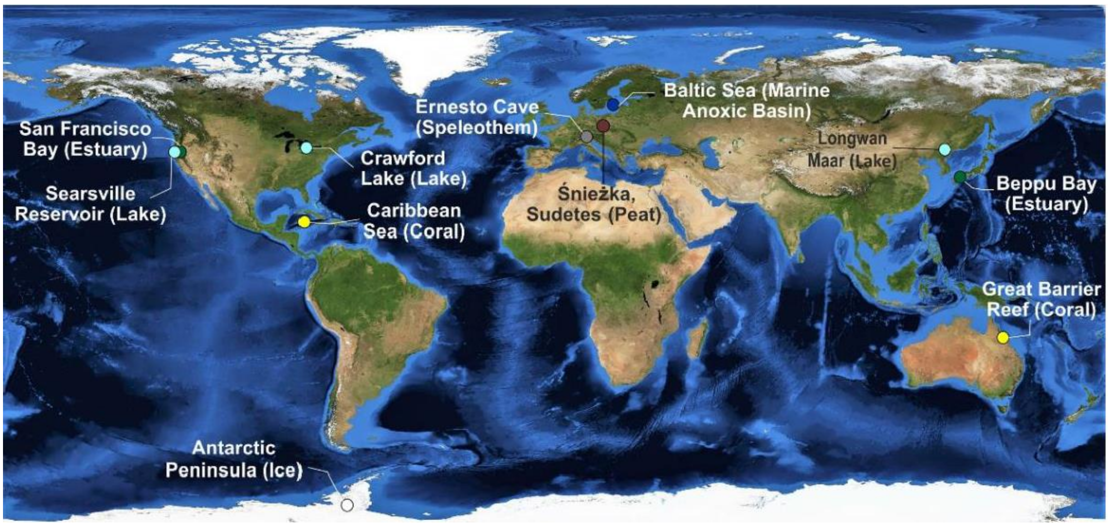


Figure 6. *Location of candidate GSSP sites, currently under investigation by the AWG (Source: AGW Newsletter – December 2020 | Available at: http://quaternary.stratigraphy.org/wp-content/uploads/2021/03/AWG-Newsletter-2020-Vol-10.pdf*

A/A	GSSP Location	Institute/s	Description of stratigraphic sequence
1	**(USA)** Searsville Reservoir California -	Stanford University USA	*The candidate GSSP core is 1103 cm long, suggesting an average deposition of ~7.5 cm/year. Computed tomography scans of the cores reveal >300 distinct layers ranging in thickness from <1mm to ~30mm.*
2	**(Czech Republic/Poland Borderline)** Na Równi pod Śnieżką peat core	Adam Mickiewicz University Poland	*A core collected from the peatland and 210Pb-dated show recent peat (0 - 49 cm) has accumulated in 149 years, corresponding to an average accumulation rate of 0.53 ± 0.11 cm yr-1. Multi-proxy geochemical work reveals the site has received trace elements and combustion products via long- and short-range atmospheric transport.*

3	**(China)** Sihailongwan Maar Lake Jingyu County, Jilin Province	Institute of Earth Environment, Chinese Academy of Sciences	*Freeze cores were collected in January 2020 along with gravity cores in September 2020. Core halves have been scanned for XRF and high-definition imagery. Subsamples have been extracted and prepared for thin-section microscopy. Varve counting has taken place with 1950 being found ~10 cm below the water - sediment interface.*
4	**(USA)** San Francisco Bay, California	University of Leicester, UK, United States Geological Survey (USGS) and British Geological Survey (BGS).	*The maximum depth of the core is 2.3 m below the bay floor. The core is composed of massive, unconsolidated silts and fine sand with occasional coarse sand and shell layers. The core represents the upper section of the Bay muds, a sequence of unconsolidated muds that date to the early Holocene which overlie coarse Pleistocene fluvial deposits.*
5	**(Canada)** Crawford Lake. Milton, Ontario	Brock University, Carleton University	*Annually laminated sediments (varves) accumulate largely undisturbed below the chemocline of this permanently stratified lake. Couplets of light-coloured inorganic calcite precipitate in warm waters of the epilimnion during summer and dark organic matter primarily derived from plankton in the fall*
6	**(Australia)** Flinders Reef, Queensland Plateau	University of Leicester, Australian Institute of Marine Science	*The coral core was cut lengthwise into 7 mm thick slices and X-rayed to reveal regular and well-defined annual density bands, which were used to establish the coral chronology. The banding allows for precise absolute age control. Samples were collected in bimonthly (1940-1992; 1940-2017), and 1-year intervals (pre-1940 until approx. 1710 A.D.) along the main growth axis*
7	**(Central Caribbean)** Little Cayman Island, Cayman Island	Geography and Anthroplogy, Louisiana State University, USA	*Coral proxies to be analyzed over a target of 300 years include carbon isotopes showing the shift in carbon isotopes in the atmosphere resulting from fossil fuel combustion that started in early 1700s, oxygen isotopes (SST and salinity), Sr/Ca, Mg/Ca, Li/Ca, Li/Mg, (temperature), δ11B (pH proxy), NO3 and δ15N (agricultural proxies), heavy metals including V (fossil fuel derivative), and Pb isotopes (pollution and fossil fuel derivative), nuclear testing products (14C, 239Pu, 241Am, and 137Cs), fly ash (black carbon), and bleaching events as biotic markers.*
8	**(Baltic Sea)** Eastern Gotland Basin	Leibniz Institute for Baltic Sea Research Warnemünde (IOW), Germany	*Core EMB201/7-4 is 45 cm in length. The lower part of the core is grey and homogenous. At about 25 cm there is a pronounced change in the lithology due to an abrupt and strong increase in the content of organic carbon. The upper part of the core is characterized by light to dark brown laminations (mm to cm scale). The abrupt lithological transition in the middle of the core marks very likely the early 1950s, which should represent the beginning of the Anthropocene.*

9	**(Antarctic Peninsula)** Palmer Ice Core,	British Antarctic Survey, Natural Environment Research Council, UK	*The core is ~133 m of ice with annual laminae extending back to c. 1617 CE. The core will have a well-resolved stratigraphy by counting annual cycles of δ18O and SO42- with confirmation against known volcanic events*
10	**(Italy)** Ernesto Cave, Trentino	University of Newcastle, Australia and University of Birmingham, UK	*Most of the studies focused on three annually laminated stalagmite records covering the last ~600 years (ER76, ER77, ER78). Each annual lamina consists of a translucent, non-fluorescent clear calcite layer and a brown thin fluorescent calcite layer enriched in soil-derived organic matter and several transition metals.*
11	**(Austria)** City of Vienna	University of Vienna, University of Applied Arts, Vienna, and Vienna Urban Archaeology	*Archaeological stratigraphy includes the 19th century fill of the Wien River channel and associated embankments and pavements, followed by foundations of a 1922 market hall, and the 1945 WWII rubble dated by its specific artefacts. Followed by the foundations of the Vienna Museum building and corresponding layers around 1956 to the modern superficial park level. The inferred 1950 - 1960 layer was verified by artificial bomb-test related isotopes such as plutonium 239.*

Table 2. *Details of the candidate GSSPs currently under investigation by the AWG for the preparation of the final proposal to ICS and IUGS (Source: AGW Newsletter – December 2020 | Available at: http://quaternary.stratigraphy.org/wp-content/uploads/2021/03/AWG-Newsletter-2020-Vol-10.pdf*

1.3.3. Further academic and peer-reviewed contributions to the Anthropocene Hypothesis

Beyond the contribution of the AWG, there is an increasing academic endeavour to establish scientific evidence of this new era which has launched three peer-reviewed scientific journals, with increasing impact factor, dedicated explicitly in research on the Anthropocene (see details in Table 3):

Journal's title	Publisher-	I. F.	Aims and scope	Vol. until 11.2021	Website
Anthropocene	Elsevier (Est. 2013)	3.964	*"Anthropocene is an interdisciplinary peer-reviewed journal answering questions about the nature, scale and extent of interactions between people and Earth processes and systems. The scope of the journal includes the significance of human activities in altering Earth's landscapes, oceans, the atmosphere, cryosphere, and ecosystems over a range of time and space scales - from global phenomena over geologic eras to single isolated events - including the linkages, couplings, and feedbacks among physical, chemical, and biological components of Earth systems."*	36 vol.	https://www.journals.elsevier.com/anthropocene
The Anthropocene Review	Sage Journals (Est. 2014)	4.182	*"The Anthropocene Review, a trans-disciplinary journal issued 3 times per year, brings together peer-reviewed articles on all aspects of research pertaining to the Anthropocene, from earth and environmental sciences, social sciences, material sciences, and humanities. High impact research articles, authoritative and stimulating reviews, and brief 'perspective' articles are especially welcome. Its overall aim is to communicate clearly and across a wide range of disciplines and interests, the causes, history, nature and implications of a world in which human activities are integral to the functioning of the Earth System."*	8 vol.	https://journals.sagepub.com/home/anr
Elementa: Science of the Anthropocene	University of California Press (Est. 2013)	6.053	*"An open access scientific journal, Elementa: Science of the Anthropocene publishes original research reporting on new knowledge of the Earth's physical, chemical, and biological systems; interactions between human and natural systems; and steps that can be taken to mitigate and adapt to global change. Elementa reports on fundamental advancements in research organized into knowledge domains, embracing the concept that basic knowledge can foster sustainable solutions for society. Elementa is published on an open-access, public-good basis—available freely and immediately to the world."*	9 vol.	https://online.ucpress.edu/elementa

Table 3. Peer-reviewed scientific journals dedicated explicitly in research of the Anthropocene

We may briefly present various significant contributions, in defence of the Anthropocene hypothesis, from academic publications and webpages dedicated to the concept, to film/documentary productions based on the main idea of mankind's epoch:

- A very interesting publication on the Anthropocene hypothesis is also the five-volumes "*Encyclopaedia of Anthropocene*", published by Elsevier in 2018 (DellaSala and Goldstein, 2018)[13]. This collective synthesis tries to scrutinize the Anthropocene hypothesis in the light of systematic and extensive review of the evidence of humanity's footprint on the natural system:
  Volume I: Geologic History and Energy
  Volume II: Climate Change
  Volume III: Biodiversity
  Volume IV: Ethics
  Volume V: Contaminants

- There are some interesting on-line applications, such as the "Anthropocene's timeline": https://www.anthropocene.info/anthropocene-timeline.php

- A special section of Stockholm's Resilience Centre is dedicated explicitly in the Anthropocene dynamics: https://www.stockholmresilience.org/research/research-themes/anthropocene-dynamics.html

- In June 2012, a film about the state of the planet opened the United Nations Earth Summit Rio+20, Globaïa's "Welcome to the Anthropocene": https://globaia.org/anthropocene

- An interesting project and documentary on the Anthropocene, produced in 2018: https://theanthropocene.org/

[13] Available here: https://www.sciencedirect.com/referencework/9780128135761/encyclopedia-of-the-anthropocene#book-description (Retrieved in 04.01.2022).

2. Decoupling Anthropocene from the Holocene; A literature review of the potential starting dates of Anthropocene

Modern human societies are functioning upon "*consuming*" enormous quantities of natural resources, while simultaneously producing enormous quantities of negative externalities, such as loads of solid and liquid waste, CO_2, and other emissions, and so on. Globalization, overpopulation and increasing urbanization are trends that further trigger more resource consumption and waste production, in a vicious cycle of increasing needs for more and more goods, while, at the same time, the negative externalities of these goods' life cycle is reshaping the earth's surface, climate, waters, and atmosphere. Human actions have been altering the biosphere since the first appearance of the homo-species. However, the last 10,000 years and, especially, the years after the industrial revolution, humanity has altered the surface of the planet physically, biologically, and chemically (McNeil, 2000). Gradually, the Mankind has been transformed, for the first time in the human history on earth, into a mighty geological agent, being comparable in magnitude to the major geological agents (Kalimeris, 2015).

Anthropogenic (manmade) flows have surpassed the geogenic (natural) flows, for various chemical elements and material types. For example, Brunner and Rechberger (2004) argue that global anthropogenic flows of cadmium (Cd) are 3 to 4 times larger than the natural geogenic flows (e.g. erosion, volcanoes, etc.) (see Fig. 7). Accordingly, McNeil (2000) gives a more remarkable comparison between major natural geophysical forces and humanity functioning as a geological agent. Specifically, according to Table 4 the average annual transportation of rock and soil is estimated between 40-45 billion tonnes from anthropogenic flows, when the wind's erosion counts for 1 billion tons, and the only natural agent remaining leader on material transport and displacement is the water, with 53 billion tonnes annually (McNeill, 2000).

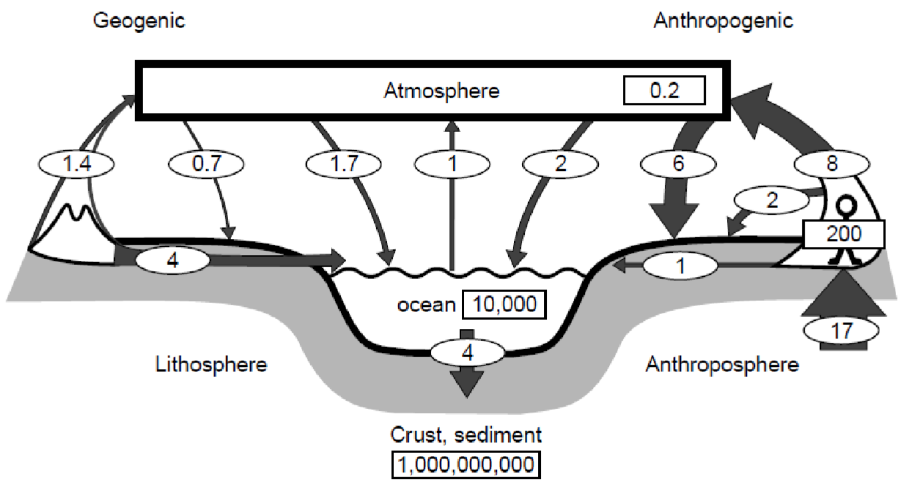


Figure 7. *Global anthropogenic versus Geogenic cadmium flows (kt/yr) in the 1980's (Source: Brunner and Rechberger, 2004-p.23)*

Natural Forces	Billion tons per year
Wind Erosion	1,0
Glaciers	4,3
Mountain building	14
Oceanic Volcanoes	30
Humanity	***40-45***
Water	**53**

Table 4. *Earth movers in 2000. The average world annual transport of Rock and Soil by humanity, compared with major geophysical agents. The table is derived from McNeil, 2000-p. 30. (reconstructed by the author)*

This anthropogenic geological force has altered the biosphere so substantially, that many distinguished scientists recognize the time period in which we live as a new geologic epoch, the so-called Anthropocene (Steffen *et al.*, 2015; Ceballos *et al.*, 2012; Gowdy and Krall, 2013).

We may define this convergence of the Anthropogenic (manmade) flows and the geogenic (natural) flows as the decoupling of the Anthropocene (manmade-unstable) upraising epoch from the Holocene (natural-relatively stable) fading epoch. We have already discussed the effort of the AWG towards the formal recognition of the Anthropocene epoch/series and the respective required amendment of the Quaternary geological time scale (Fig. 8).

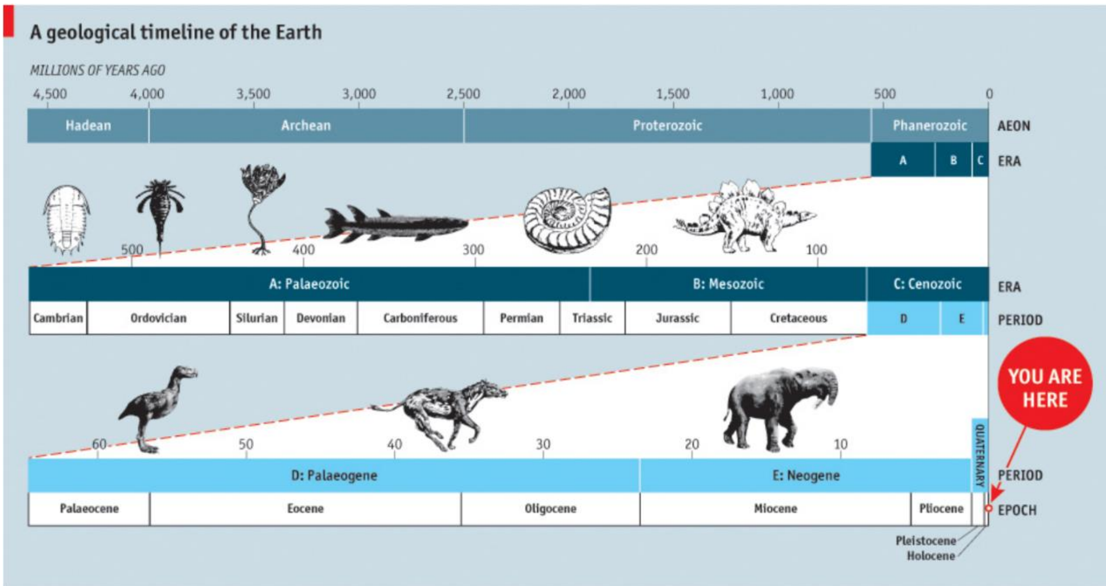


Figure 8. *A graphical geological timeline of the Earth. (Source: The Economist, 2011. Available at: https://www.economist.com/briefing/2011/05/26/a-man-made-world?story_id=18741749 - Retrieved at 28.04.2021).*

Accordingly, Figures 9 and 10 depict how a potential amendment of the formal ICC would look like. Towards this direction, the key question of the present section is to define the potential starting points of when this continuous decoupling (between the Holocene and the Anthropocene) may initially occurred. It goes without saying, that the adoption of a formal and widely recognized GSSP is the first critical step towards the recognition of this new epoch. Through the last two decades of research, the definition of one solely GSSP for the Anthropocene's starting point remains yet an open debate. The various approaches and the different proposals are calling for an overall evaluation and the consideration of different arguments, aspects, and stratigraphic evidences.

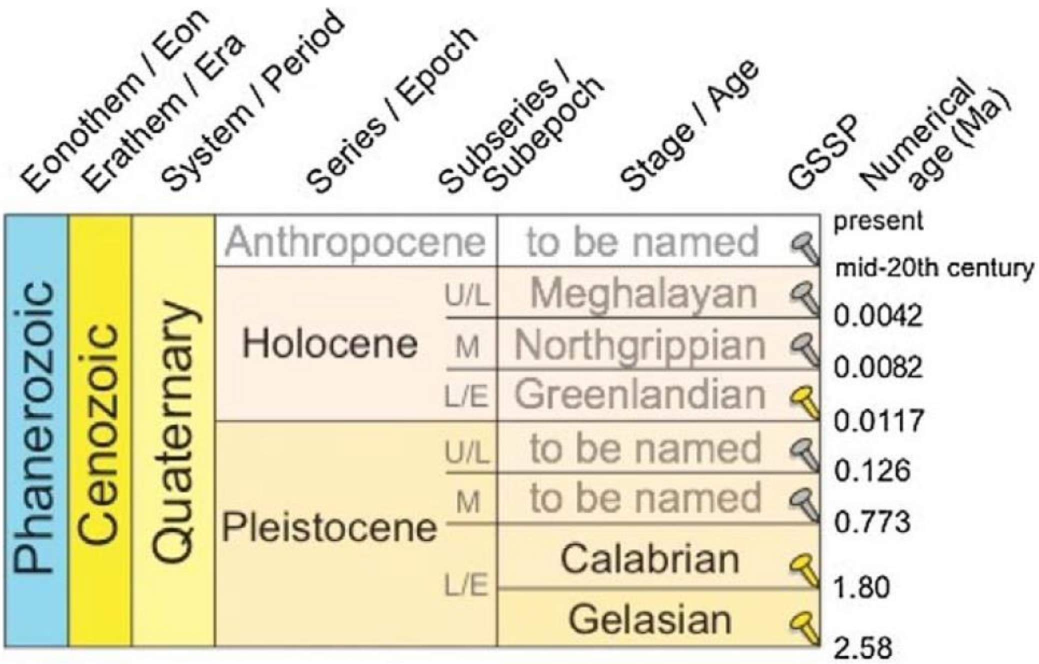


Figure 9. *The Quaternary time scale as currently preferred by the AWG, with the Anthropocene shown at the rank of series/epoch. (Source: Zalasiewicz et al., 2017).*

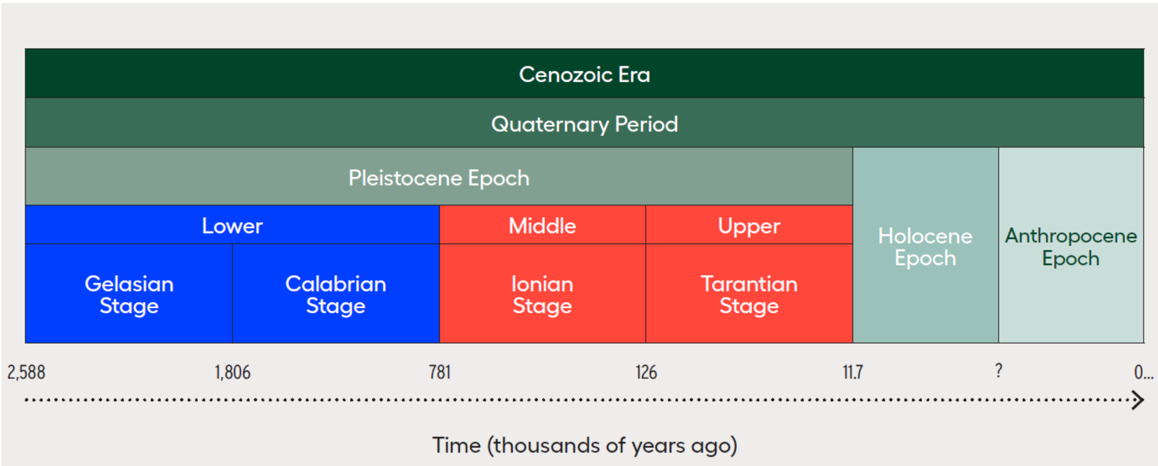


Figure 10. *Another graphical representation of the Quaternary time scale, with the addition of the Anthropocene epoch/series (Source: Malhi, 2017).*

A first critical step to review the huge relevant literature, would be to distinguish our analysis in two phases, according to Malhi (2017):

1. **The informal conception**

   The vast majority of the published studies, consisting of the main body of informal scientific proposals and analysis. This would be the scope of the present section.

2. **Towards a formal adoption and definition**

   The official working group of AWG, preparing the final proposal to be submitted for recognition to the ICS and, finally, to the IUGS, already discussed in detail, in the previous section.

Apparently, the "*scientific tank*" of the "*informal conception*" literature provides a constant additional feedback to the "*formal adoption and definition*" work of AWG, enhancing its argumentation and shaping the evidences from around the globe. This controversial "*informal conception*" scientific debate has derived so far, several different starting dates, reflecting different disciplinary, interdisciplinary, and intradisciplinary perspectives, evidence, and criteria regarding when human impact first began to play a significant role in shaping the earth's system. This challenging process has also inspired various other proposals acting as substitutes or/and complements to the main Anthropocene Hypothesis.

We may distinguish the relevant literature in two branches:

1st Branch: Focuses mainly but not exclusively on the so-called "*Agricultural Revolution*". Covers almost the entire Holocene and, in some cases goes back to the discovery of fire and the megafauna extinctions. We may distinguish the first branch as the **macro-Anthropocene hypothesis**.

2nd Branch: Covers the extremely short, in terms of geological time, period with proposed potential turning points, such as: the beginning of the colonization era, the 1st Industrial Revolution, the nuclear bombs testing, and the so-called period of "*Great Acceleration*". We may distinguish the second branch as the **micro-Anthropocene hypothesis**. The next sections discuss in detail these two branches.

2.1. The Macro-Anthropocene hypothesis: Agricultural revolution, quest for fire, and other proposals

2.1.1. The use of fire

Logging for primitive human impacts on the environment, perhaps someone ought to begin the research with the very first "*promethean*[14]" energy input that humans used to satisfy their needs, the prehistoric use of fire (McNeill, 2000). Numerous debates over the first regular use of fire by early hominins in Africa, claim that this probably be occurred somewhere between 1.6 to 1.8 million years ago, however there is no homogenous evidence for simultaneous use of fire at the global level. For example, archaeological evidence suggests that the earliest evidence for habitual use of fire in Europe is traced much more later than Africa, approximately between 300,000 to 400,000 years ago (Roebroeks and Villa, 2011). Indeed, fossil charcoal captures traces of this early anthropogenic use of fire from the Early Pleistocene epoch (Glikson, 2013). Towards this direction, others propose new terms, such as "*Palaeoanthropocene*" to name the period between the first anthropogenic environmental changes (use of fire; agriculture, etc.) and the industrial revolution, when the human impact started increasing dramatically (Foley *et al.,* 2013).

Nonetheless, the lack of any simultaneous global evidence, the big differences between the starting points of fire utilization by humans per continent, as well as the locality of the existing evidence, do not provide evidence for a global stratigraphic golden spike. In that sense, setting the starting date of the Anthropocene epoch sometime after the Early Pleistocene seems rather too vague.

2.1.2. The great Megafauna extinction

Doughty *et al.*, (2010), using pedosphere analysis, suggest that the onset of Anthropocene should be extended back until 13,800 BP, where a megafaunal predation and vegetation change was occurred. Notwithstanding, again this proposal exceeds the Holocene epoch and, thus, it would be extremely difficult to be accepted

[14] The term "Promethean gift" was introduced to the relevant natural resource scarcity debate in environmental economics, by the great Romanian Economist Nicolas Georgescu-Roegen, in the 1970s.

as a formal proposal for approval. However, in a next section we examine in detail the interesting hypothesis of the currently ongoing sixth mega species extinction.

2.1.3. The so-called Agricultural Revolution – The expansion of farming

Some researchers propose the early-anthropogenic hypothesis, based mainly on the evidence provided by land use changes, early methane and CO_2 emissions increment, triggered by the gradual domestication of crops and livestock by humans, started about ≈ 13,000 – 10,000 years BP, known as the Agricultural Revolution (Ruddiman, 2003; 2007; 2013) (see e.g. Fig. 11 for the global spread dynamics of agricultural revolution). Again, the Agricultural revolution is not a homogenous event (like the use of fire); it occurred in different long-run periods through time and across continents, from the early Mesopotamia and North China spread, to the much later spread in central- south Africa and North-South America (Fig. 11 and the more detailed Figs. 12a & 12b).

Ruddiman (2013) supports the view that the preindustrial anthropogenic warming, created by human domestication of crops and livestock, was larger than the observed human-induced warming to date, during the industrial revolution until the present.

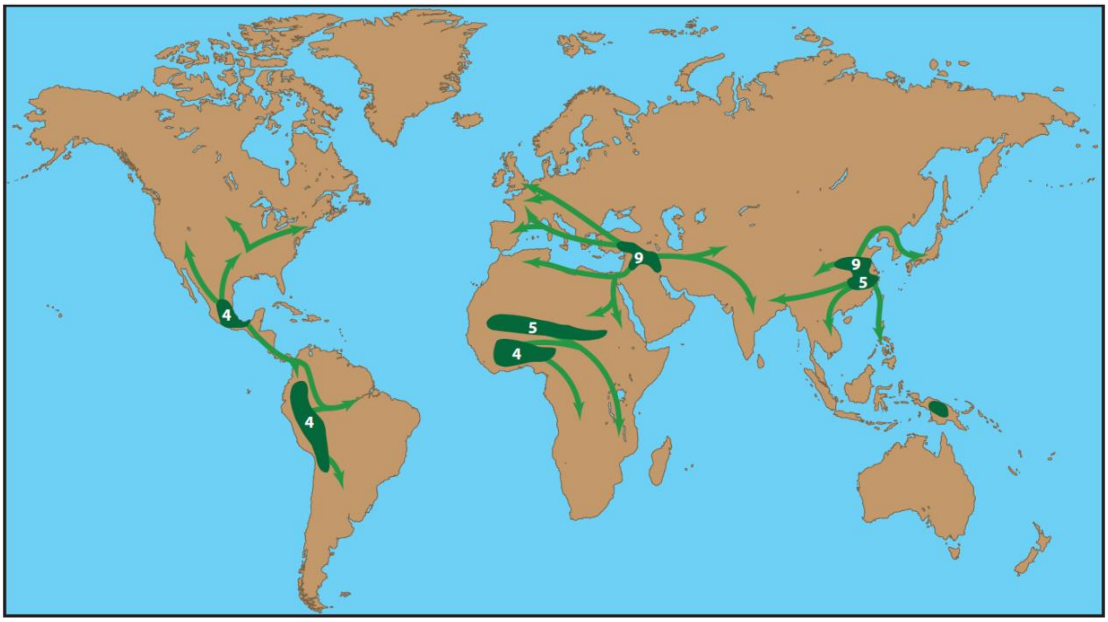
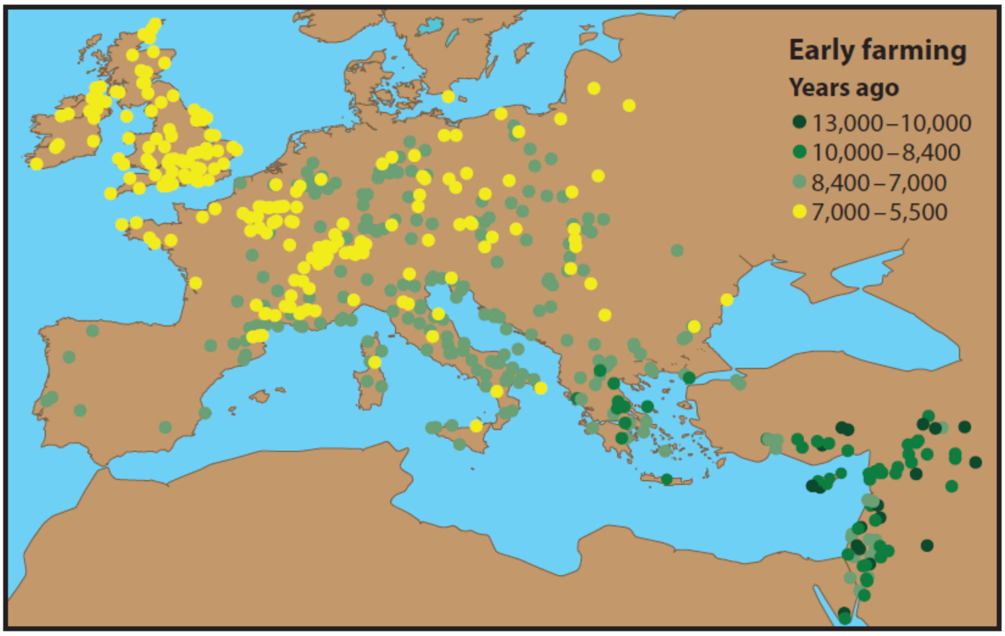


Figure 11. *The spread of agriculture from several centres of origin during the past 10,000 years. Numbers in white font mark the time in thousands of years of the initial spread from centres of origin (From Ruddiman, 2013 – p. 48)*

a.



b.

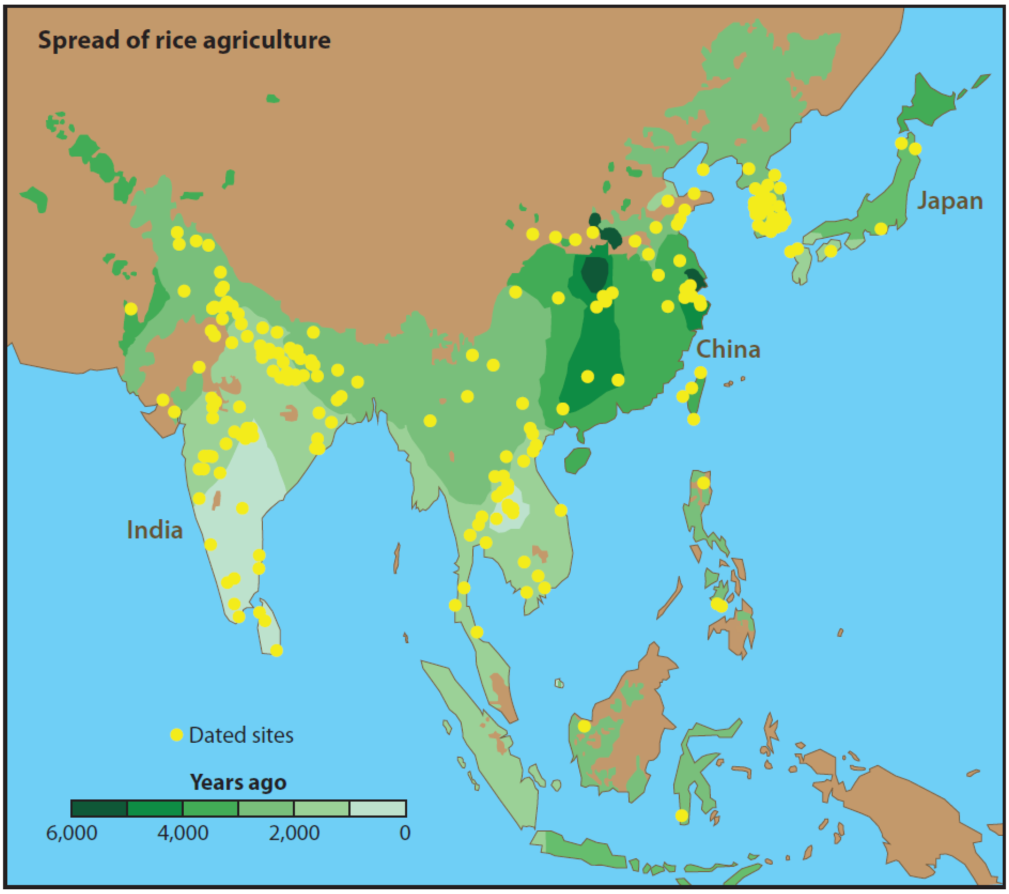


Figure 12. *Evidence of early farming spread a) in Europe and Southwest Asia (Zohary and Hopf 1993), and b) evolution of irrigated rice cultivations across southern Asia – China, India, Japan, etc. (Fuller et al., 2011). (All prototype figures derived from Ruddiman, 2013 – p. 48-49.)*

Towards this direction, others claim that increases in CO_2 concentrations in the atmosphere, occurred around 6,000–8,000 years BP by human agriculture, which converted high-carbon storage flora (e.g. forests) to crops and grazing lands, and the extensive use of fire as a tool for rapid altering in land uses, postponed the new glaciation period (Glikson, 2013). Nevertheless, this hypothesis is still an open debate, with others questioning the actual atmospheric human impact for so many thousand years BP (Broecker and Stocker, 2006; Stocker *et al.,* 2011). It seems that the human-induced CO_2 hypothesis during the agricultural revolution is difficult to provide a possible GSSP with global evidence.

From the interdisciplinary perspective of ecological economics, Gowdy and Krall (2013), argue that during the agricultural transition human societies started functioning as superorganisms, through the invention of complex labour division methods and continuous population growth, which led in intensive natural resource exploitation and depletion, setting the socio-economic and demographic roots of the Anthropocene hypothesis in the Agricultural Revolution.

2.1.4. The pedosphere's analysis and the early anthropogenic CH_4 hypothesis

Certini and Scalenghe (2011) propose the use of pedosphere, as the best soil layer recording human-induced modifications of the earth system, suggesting that the starting point of Anthropocene should be placed 2,000 years before present (hereinafter, B.P.[15]), thus in the late Holocene, when the natural state of much of the terrestrial surface of the planet was altered appreciably by organized civilizations.

More radically, Ruddiman and Thomson (2001) are focusing on a much earlier increase in methane (CH_4) in the Greenland ice core record and arguing that around 5,000 B.P., when human societies begun to have a detectable influence on the earth's atmosphere, called their observation ''*early anthropogenic CH_4 hypothesis*''. Even though they do not use explicitly the term Anthropocene, though, they label the time

[15] For more in the use of B.P. as geological and archeological time scale, see also: https://en.wikipedia.org/wiki/Before_Present

span from 5,000 B.P. to the beginning of the industrial revolution as the "*early anthropogenic era*". Indeed, CH_4 (hereinafter, methane) analysis seems more promising, as it may provide a potential GSSP at 5,020 years BP, the date of the lowest methane value recorded (Blunier *et al.,* 1995). According to Table 5 (Annex II of the 2nd Chapter) rice cultivation in Asia and archaeological evidence of expanding populations of domesticated ruminants may suggest a potential "*golden spike*" for macro-Anthropocene's starting point.

2.2. The Micro-Anthropocene hypothesis; pre-industrial colonization era, the 1st Industrial revolution (1750-1800), and the Great Acceleration.

2.2.1. The pre-industrial colonization era – the year 1610

Lewis and Maslin (2015) provide an extensive literature review on Anthropocene and they suggest, for the first time in the history of the relevant debate, the collision of the Old and New Worlds, as a possible GSSP, to mark the beginning of the Anthropocene. More specifically, they (ibid) suggest the year 1610 as the beginning of the Anthropocene, due to the very fact that, after the discovery of the American continent (the New World) in 1492, humans interconnected in both hemispheres in the largest population displacement in human history, trade become gradually global by establishing enormous networks, unifying the continents, from America to Asia, Oceania and Africa, and an the unprecedented homogenization through mixing of Earth's, separate before that point, biota, with geological implications, known as the so-called "*Colombian Exchange*" (Crosby, 2016) (see also Table 5 - Annex I of the 2nd Chapter). The selection of the year 1610 is not a random guess; on the contrary, empirical evidence provided by Antarctic ice cores showed a dramatic decrement in atmospheric CO_2 levels in the selected year[16]. It is assumed that this dip in the atmospheric CO_2 was triggered by the massive reductions in human population by the

[16] 7–10 p.p.m. dip in atmospheric CO_2 to a low point of 271.8 p.p.m. at 285.2m depth of the Law Dome ice core, dated in 1610 (±15 years) (Source: Lewis and Maslin, 2015 – p. 175).

diseases brought the colonizers to the New World, which killed more than 50 million people, largely by smallpox. Because most of the indigenous people where farmers, when land's cultivation halted because of massive deaths, forests were able to grow back again and thus function as carbon dioxide sinks. The year 1610 seems to be an essential historical and geological boundary, documenting global changes in climate, chemistry, as well as geology.

2.2.2. the 1st Industrial revolution (1750-1800)

The advent of the Industrial Revolution, around 1800, provides a popular starting date for the new epoch, coinciding with James Watt's steam engine invention, in 1784 (Crutzen and Stoermer, 2000; Crutzen, 2002, 2006; Steffen *et al.,* 2011; Zalasiewicz *et al.,* 2011). Crutzen and Stoermer (2000) were initially placing the beginning of the Anthropocene sometime between 1750–1800, based on evidence of accelerating increase in carbon dioxide and methane provided by the ice core records.

2.2.3. The Great Acceleration – from the WWII's end to the nuclear energy and plastics

The so called "*Great Acceleration*" period marks the excessive economic growth and the respective excessive exploitation of natural resources (mainly fossil fuels) followed the devastating WWII consequences. The period starting circa 1950, is recognized as the starting point of this acceleration (Ludwig and Steffen, 2017; DellaSala *et al.*, 2018, Elias, 2018). Another essential aspect of this period is also the simultaneous recognition of stratigraphic markers that may provide evidence for the identification of the Anthropocene. According to Zalasiewicz *et al.* (2016), we may identify the following stratigraphic markers:

- Artificial radionuclides
- aluminium metal
- fly ash particles
- persistent organic pollutants
- various other biological indicators

We may add the plastic materials as another potential stratigraphic market of the great acceleration (plastics are discussed in more detail in a following section). In the following subsections, we distinct our analysis in two subperiods: after 1945; and after 1963.

2.2.3.1. After 1945 – WWII's ending

Only beyond the mid-20th century, thus, year circa 1950, there is clear evidence for fundamental shifts in the state and functioning of the Earth System that are beyond the range of variability of the Holocene and, consequently, driven by human activities. Thus, of all the candidate starting dates for the Anthropocene epoch, the *Great Acceleration* is by far the most convincing, from an Earth System science perspective (McNeill and Engelke, 2014; Waters *et al.,* 2015; Steffen *et al.* 2015; Odada *et al.,* 2020). (See also the *Planetary Boundaries* framework, presented in the next chapter)

2.2.3.2. After 1963 – first nuclear bomb testing

This category is based on the identification of measurable amounts of artificial radionuclides which are associated with atomic detonations, as potential global GSSP's proposal for the empirical evidence of the Anthropocene (Zalasiewicz et al., 2008; Ευθυμιόπουλος, 2017). According to Lewis and Maslin (2015), the reliable detection of 129I in high-resolution glacier ice and the expanding number of locations at which novel minerals, compounds and other recent human signals are discovered, would advance the "*1964"* GSSP proposal. For the authors (Ibid), the selection of 1964 as the initial point of the Anthropocene epoch is the most appropriate to record the human impacts during the "*Great Acceleration*" era, since stratigraphic records of the recent past hide some interesting markers of human activities and, consequently, is better to focus there, than back in the *Industrial Evolution,* or, even earlier, back in the *Agricultural Revolution*. However, the authors (Ibid) recognize a disadvantage of this selection, as although nuclear explosions have the power to potentially transform the Earth system, so the radionuclide marker as a GSSP is not yet, fortunately we might say, a mega-changing event. After all, from a cynical perspective, a global radionuclide marker establishment may mean that there are no humans left around to record it!

2.3. Concluding remarks

The brief literature review of the present section reveals one fundamental problem: the numerous proposals of various interdisciplinary approaches at both the macro and the micro levels of the Anthropocene hypothesis. Probably, the expansion of the research time span at the macro-Anthropocene level lacks sufficient stratigraphic evidence and requires brave amendments of the ICS, which would never be accepted by the formal scientific bodies of ICS and IUGS. In that sense, the convergence of the derived literature towards a more realistic approach is of paramount importance and, consequently, the AWG's work should bridge these differences and highlight the most important ones.

According to Ruddiman (2013), one possible solution to the problem of setting a starting date to Anthropocene could be the distinction of two long-run phases/periods, rather than a strict starting point:

1. An early anthropogenic impact that began during the agricultural revolution and slowly grew up essentially, by the end of preindustrial time (See Annex III).

2. A later explosive anthropogenic impact during the industrial revolution (approximately 1750-1800) until now (See Fig. 13).

Following the concluding remarks of Lewis and Maslin (2015), we may exclude three potential GSSP turning points:

- The earliest potential GSSP is the conjugation of atmospheric methane at approximately 5,020 years BP (Annex II; Table 5). Nevertheless, the authors provide arguments against the adoption of this turning point, due to the lack of correlated auxiliary stratotypes.

- As a result of the unprecedented movement of species (global biota homogenization), atmospheric CO_2 decline to a historical minimum and the resulting climate changes within various stratigraphic records supporting this evidence (Fossil crop pollen, phytoliths, charcoal, etc.), the authors (ibid) propose the so-called "*Orbis spike dip*"[17] in CO_2 with a minimum at 1610, as a potential GSSP turning point for Anthropocene.

- The so-called "*Bomb pulse*[18]" is the sudden increase of radiocarbon (^{14}C) atmospheric concentration, because of the extensive nuclear weapons testing during 1950 until early 1960s, during the cold war's armament race. This massive nuclear use temporarily doubled the natural concentration of radiocarbon in the atmosphere, creating a dramatic pulse that labelled everything alive since 1955, as carbon moved up the food chain (Buchholz et al., 2018). In that sense, **1964** peak in radiocarbon appears to fulfil the criteria for a global GSSP and, thus, is proposed as a potential turning point of the Anthropocene.

The aggregate contribution of both early (macro) and later (micro) anthropogenic trends might explain the modern observations in human-induced climate change, according to Fig. 13 (ibid.). By all odds, an effort to bridge the macro with the micro Anthropocene analysis would probably cause strong objections by many geologists, as stratigraphically inappropriate and geologically shallow. Perhaps this early macro-Anthropocene viewpoint could serve more as an introductive narrative leading gradually to the formal, and maybe most appropriate, micro-Anthropocene viewpoint which has more sound GSSP basis and, thus, it is more likely to emerge "*white smoke"* from the chimney atop ICS' and IUGS' "*priesthood"* of formal recognition.

Figures in ***Annexes II & III*** illustrates graphically all the above-mentioned argumentation on the potential Anthropocene's starting points.

[17] See also: https://www.cnet.com/news/orbis-spike-in-1610-marks-date-when-humans-fundamentally-changed-the-planet/ (Retrieved in 24.11.2021)
[18] See for more:

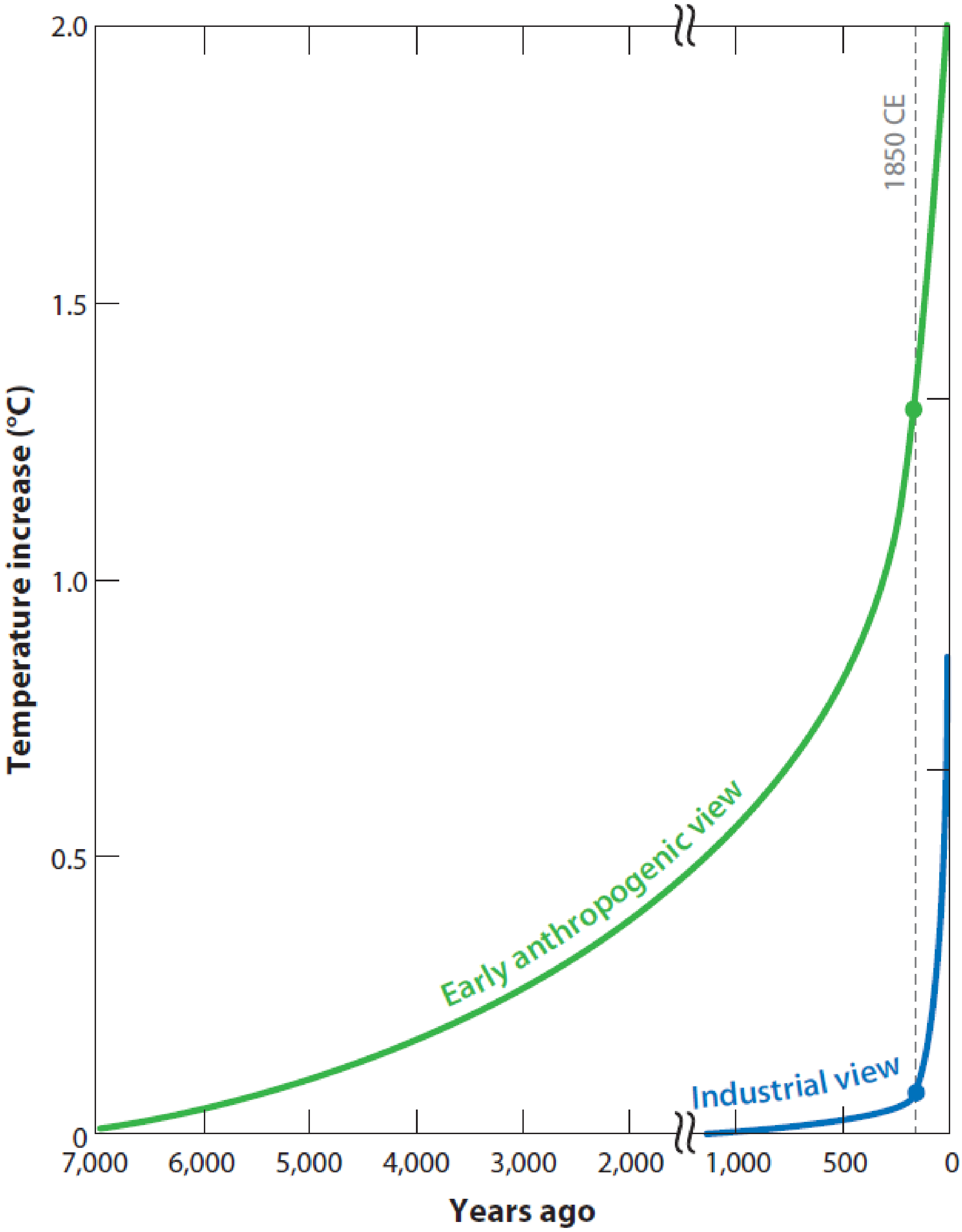


Figure 13. *Trends of temperature increases during early and later anthropogenic impacts (Source: Ruddiman, 2013)*

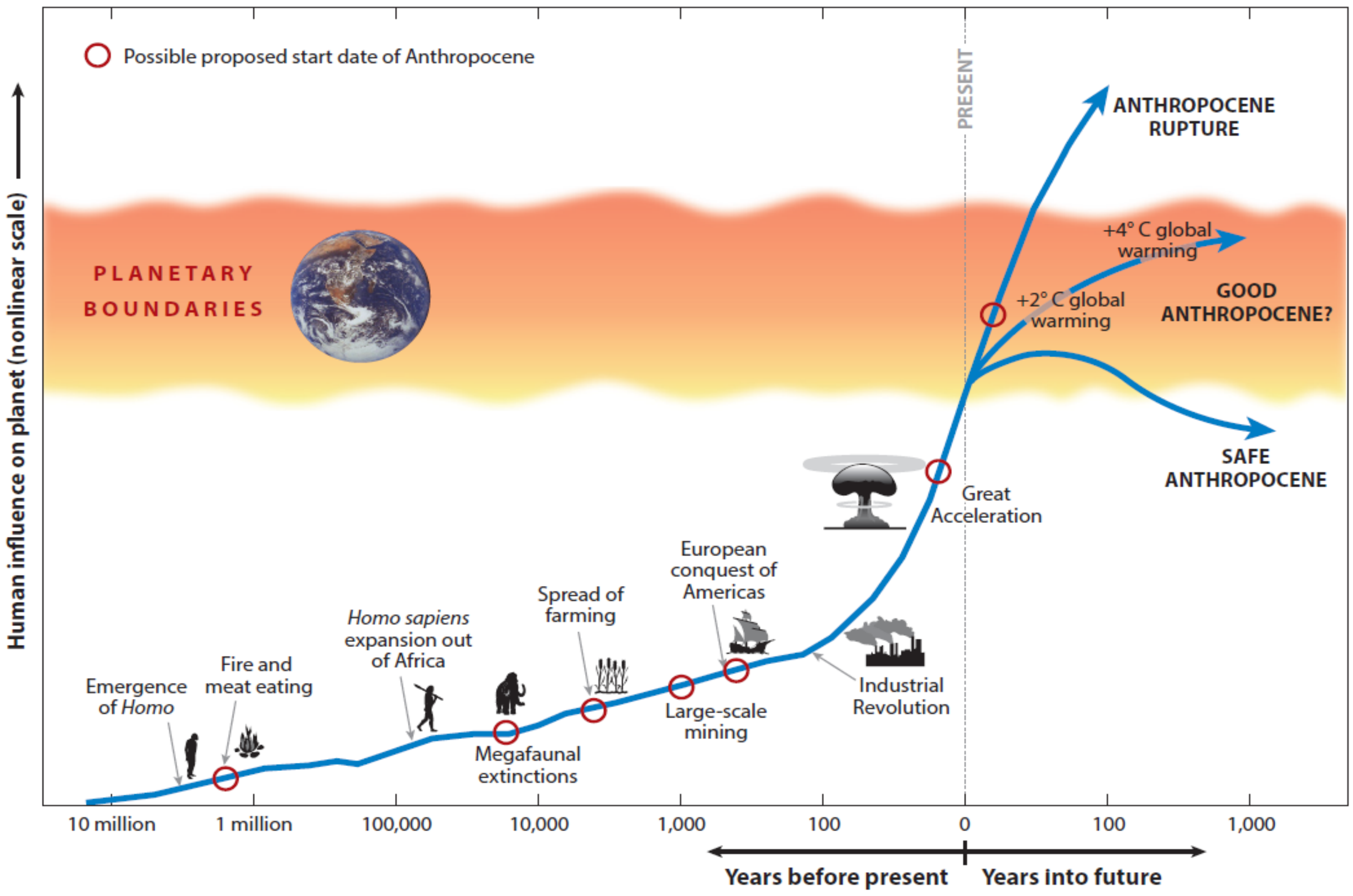
Annexes I - III of the 2nd Chapter

Annex I

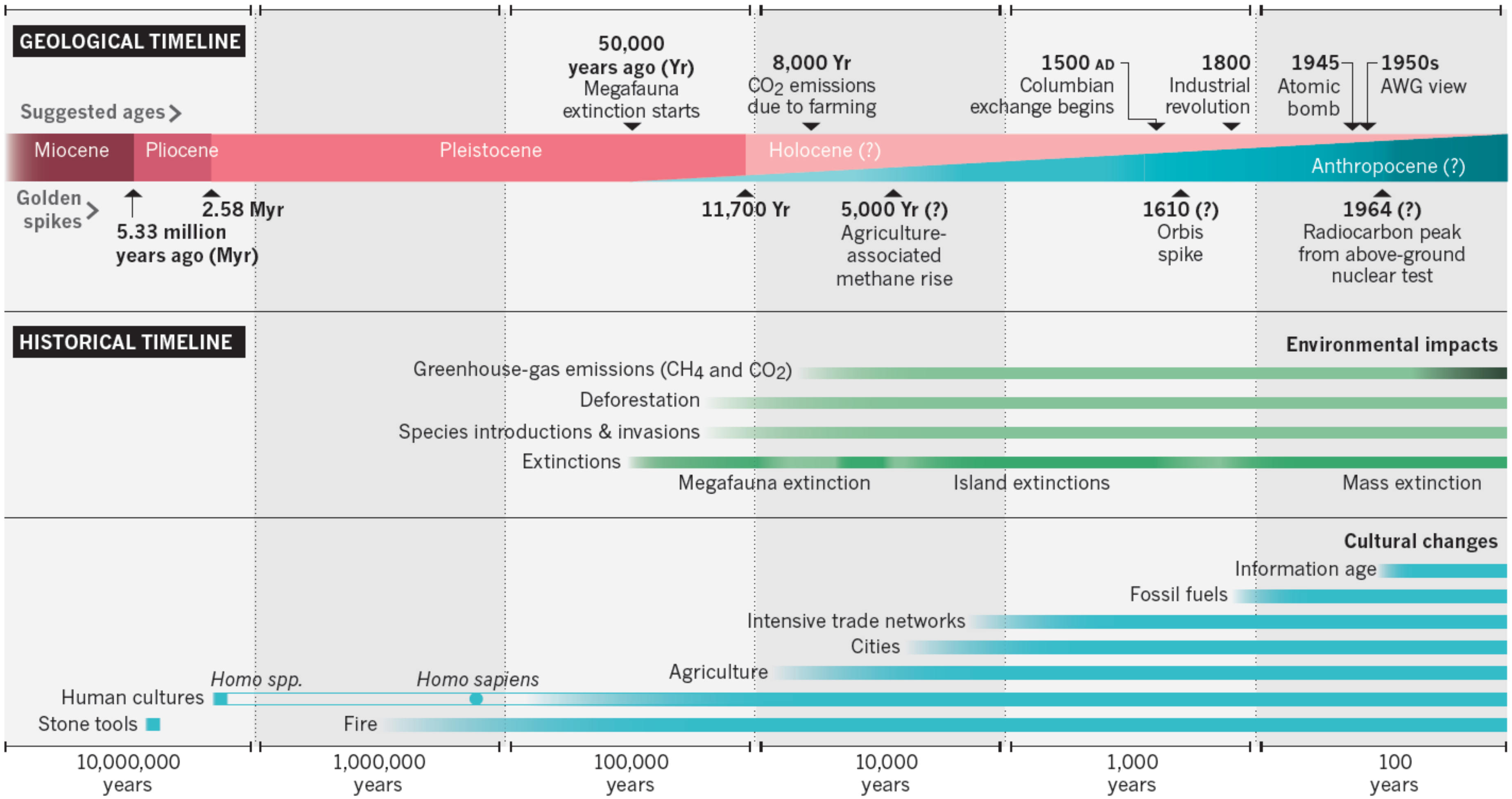
Event	Date	Geographic extent	Primary stratigraphic marker	Potential GSSP date	Potential auxiliary stratotypes
Megafauna extinction	50,000 – 10,000 years BP	Near-global	Fossil megafauna	None – diachronous over 40,000 years	Charcoal in lacustrine deposits
Origin of farming – Early Agricultural Revolution	≈ 11,000 years BP	Started in southwest Asia and, gradually became global	Fossil pollen or phytoliths	None – diachronous over 5,000 years	Fossil crop pollen, phytoliths and charcoal
Extensive farming	≈ 8,000 years BP until now	Eurasian event, **global impact**	CO_2 inflection in glacier ice	None – inflection too diffuse	Fossil crop pollen, phytoliths and charcoal, ceramic minerals
Rice production	6,500 years BP until now	Southeast Asian event, **global impact**	CH_4 inflection in glacier ice	5,020 years BP CH_4 minima	Stone axes, fossil domesticated ruminant remains
Anthropogenic soils	≈ 3,000 – 500 years BP	Local event, local impacts but widespread	Dark high organic matter soil	None, diachronous, not well preserved	Fossil crop pollen
New-Old World collision	1492-1800	Eurasian – American event, **global impact**	Low point of CO_2 in glacier ice	1610 CO_2 minima	Fossil crop pollen, phytoliths and charcoal, CH_4 speleothem δ^{18}, tephra
Industrial Revolution	1760 to present	Northwest Europe event, local impact, **becoming global**	Fly ash from coal burning	1900, diachronous over 200 years	^{14}N:^{15}N ratio and diatom composition in lake sediments
Nuclear weapons	1945 to present	Local events, **global impacts**	Radionuclides (^{14}C) in tree rings	1964 ^{14}C peaks	^{240}Pu:^{239}Pu ratio, compounds from cement, plastic, lead and other metals
Persistent Industrial Chemicals	1950 to present	Local events, **global impacts**	e.g. SF_6 peak in glacier ice	Peaks often very recent, difficulty in accurate dating	Compounds from cement, plastic, lead & other metals

Table 5. A brief representation of potential start dates for formal Anthropocene Epoch (Source: Lewis & Maslin, 2015 – p.175 – reconstructed by the author)

Annex II Potential starting dates of the Anthropocene. Source: (Source: Malhi, 2017 – p.90).



Annex III Geological timeline with potential Anthropocene's golden spikes and historical timeline of environmental impacts and cultural changes, trough time. (Source: Ellis *et al.,* 2016 – p. 193)



3. Human – Natural trends in the era of Anthropocene.

Chapter two focused mainly on the relevant literature dealing with both the macro and the micro Anthropocene streams of studies, proposing potential starting points of the new epoch. There are other interesting approaches categorizing the Anthropocene hypothesis under the spectrum and the argumentation of different disciplines, such as (Malhi, 2017):

1. The Perspective of Earth Sciences
2. The Ecological perspective
3. The Geological perspective

In the present thesis, we adopt the most updated approach of the official endeavour towards formal recognition, the proposal of AWG for the so-called "*Great Acceleration*", approximately after WWII, circa 1950 (Zalasiewicz *et al.*, 2016; Ludwig and Steffen, 2017; DellaSala *et al.*, 2018, Elias, 2018; Zalasiewicz and Waters, 2018; Tarolli *et al.*, 2018). The present Chapter aspires to provide evidence in favour of the "*circa 1950*" proposal. To achieve this, we may categorize our analysis in two distinct categories, following the main conception of Steffen *et al.* (2015):

- **The Socio-Economic trends**:
  Namely, the fundamental trends in human population, economic growth, energy and material consumption, food production and global trade, and plastics production.

- **The Earth System trends:**
  Namely, the CO_2 emissions, Ozone layer depletion, biodiversity loss, eustatic sea level rise, ocean acidification, and Atlantic Meridional stream disturbances. Finally, we present one of the most beyond-the-state-of-the-art methodologies quantifying the Earth system's trends, the so-called *"Planetary Boundaries"* concept of the Resilience Centre of the Stockholm's University.

3.1. The Socio-economic trends: Holocene on the verge; tracing human footprint in Anthropocene

The modern civilization is coupled with an insatiable hunger for energy and materials. Evidently, the miracle of modern "*energy-material mega-consumer & mega-polluter*" civilization starts in England, where coal gradually substitutes wood, the predominant fuel material since prehistoric times. The unparalleled structural changes this transition set off, spread progressively from the UK in North-Western Europe, to the rest of the North Europe and the North America, and it was based almost exclusively on fossil fuels consumption (Kalimeris, 2015). According to Smil (2014), besides the enormous consumption of fossil fuels and metal ores, we should not overlook the unprecedented enormous quantities of construction materials that had to be extracted, processed, transported, and, eventually, incorporated in bricks, cement and concrete, to build the essential infrastructure of the modern economies (such as roads, railways, ports, airports, mines, factories, settlements, buildings, etc.). The modern energy-material era triggered the constant creation of new needs[19], leading into the invention of new materials, such as asphalt roads (after 1900, due to the constantly increasing use of cars), cement and steel, paper, silicon and plastics (plastic is probably, the most representative artificial material of the 20th century which successfully replaced wood, metals, zinc, tin and glass). Finally, the unparalleled progress in chemical engineering led to the invention of numerous other innovative materials such as polyamides and polycarbonates, as well as the synthetic fertilizers, while the early nuclear bomb testing led into the manipulation of nuclear energy for electricity production in many countries (Kalimeris, 2015).

Undoubtedly, these socio-economic trends reveal the indirect impact of the human systems on the natural systems, reflecting the anthropogenic origins of the current era. Evidently, it seems that the Holocene series/epoch is on the verge, on the brink

[19] There is an increasing literature criticizing modern economic system for creating artificial needs, through marketing and packaging technics, leading into more consumption of numerous unnecessary goods, services, and gadgets, thus resulting in additional environmental pressure and resource depletion (For more see: Kalimeris, 2018). In any case, this issue remains beyond the scopes of the present thesis.

of a new age, highly affected by the human systems at the global level. In that context, the present subsection investigates the human footprint of the Anthropocene, as it is reflected in the trends of some critical variables of the socio-economic system: human population; GDP; energy and material consumption; food production; and plastics consumption.

3.1.1. The growth of human population

Evidently, human population's growth remains an essential driving factor of tracing the impact of human footprint. Population variable reflects the indirect consumption of natural resources, and the respective negative externalities (pollution, waste, emissions, etc.) accompanying the production process, to preserved and increased through time. Figure 14 provides a historical evolution of human population, from the late *Stone Age* (≈ 7,000 BP) until the *Industrial Revolution*.

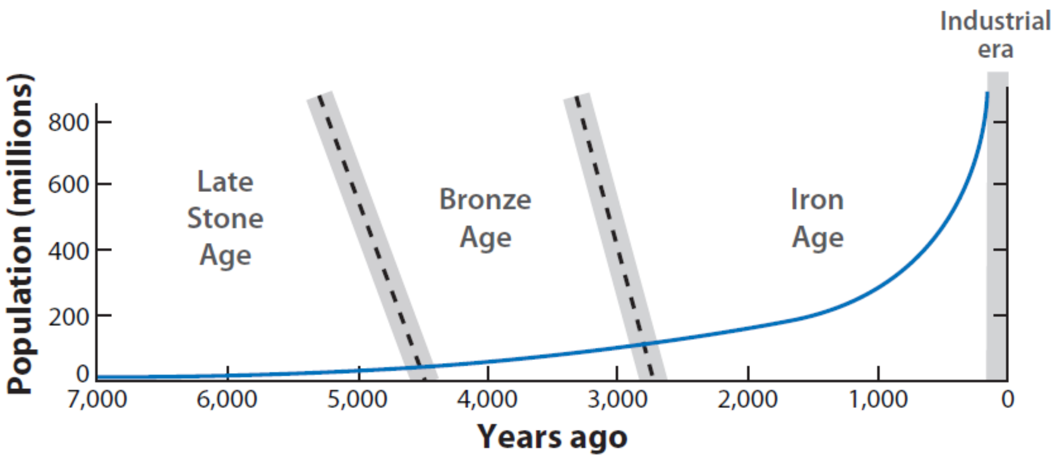


Figure 14. *Estimated evolution of the global human population through the Agricultural Revolution until the Industrial Revolution (Source: McEvedy and Jones, 1978 – Retrieved by Ruddiman, 2013 – p.50)*

We observe a rather stable population growth trend, with a hint of smooth increasing, throughout a period of six thousand years ago. Evidently, global population remains, until the end of the so-called *Iron Age*, below 800 million persons. However, focusing explicitly in the last 2,000 years (See Fig. 15), we realize that the remarkable event which led in the exponential growth of human population, was indeed the *Industrial Revolution*, yet the most intricated turning point is observed by the end of WWII and the *Great Acceleration* period starting circa 1950. According to the historians McNeill and Engelke (2014 – p. 41), it took thousands of years for our homo sapiens species to reach the first one billion of population, around 1800 to 1820, and only one century to reach the second billion by 1930. In only thirty years, in 1960, we have reached three billion, while only in fifteen years we have reached the fourth billion. Evidently, the two thirds of human population growth, the bigger number of living humans ever existed on Earth, took place between 1945-2015 (ibid). The extraordinary technological booming occurred by the massive exploitation of natural resources (mainly fossil fuels), after 1945-50, triggered a dramatic and unprecedented growth of human population, from less than a billion, in the beginning of the industrial revolution, to more than 7.5 billion people today, whilst projections in global population estimate almost 9 billion people sometime between 2030-2050[20].

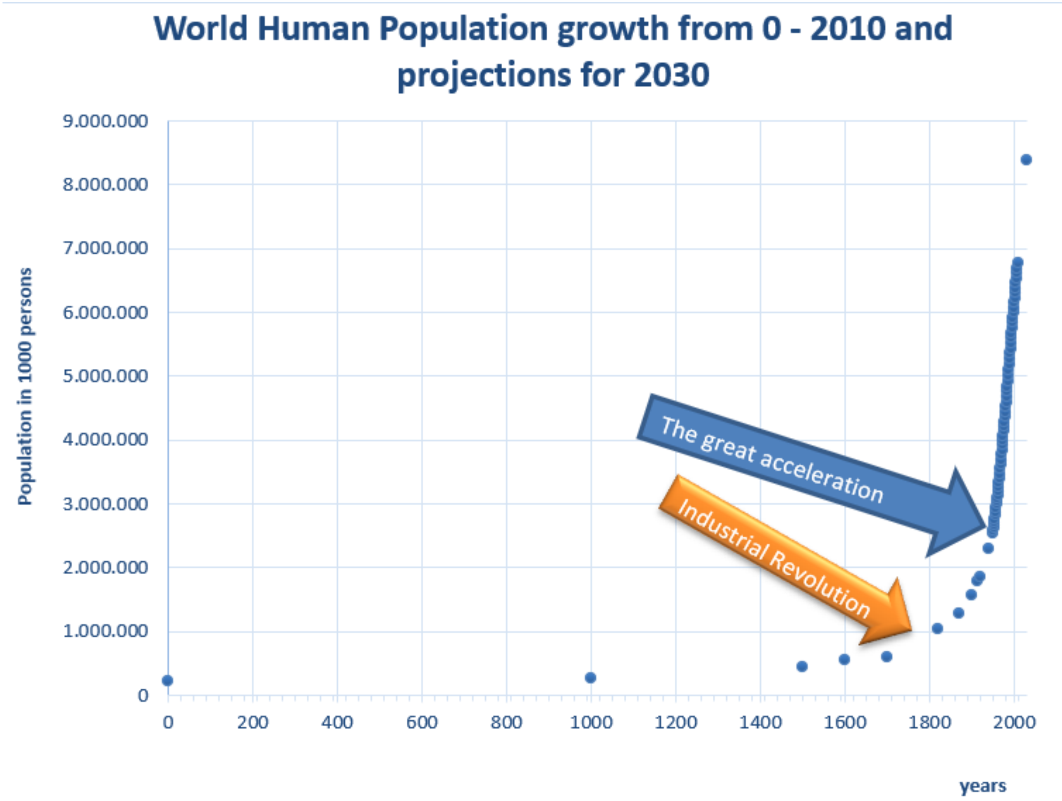


Figure 15. *Estimates of the evolution of global population, from year 1 until 2010 and projections until 2030 (Figure constructed by the author, data source: Maddison Database 2010 – University of Groningen: https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-database-2010)*

[20] https://population.un.org/wpp/ (Retrieved in 20.02.2022)

Evidently, the dominance of human species on Earth, reflects the remarkable impact of human civilization on the natural system, for the first time in our diachronic presence on Earth. The socio-economic trends driven by this extraordinary population growth will be further analysed in detail, in the next sections. Remarkably, population growth is followed by an extremely increased exploitation of natural (energy & material) resources, ecosystems services, biodiversity, and other critical elements of the biosphere, such as atmosphere, ocean, and soil absorption capacity. The importance of demographic analysis lies on the fact that humans in modern societies, apart from the direct food calories and water consumption, indirectly "consume" natural resources, (material and energy) for housing, cooking, transportation, heating, etc. Additionally, humans consume goods and services derived by a complex socio-economic system providing, infrastructures, buildings, electricity grid, highways, harbours and airports, railways, markets, industries, water, electricity and sewage pipes network, health and education systems, civil protection and national defence systems, to mention some indicative examples, all summing up in the enormous manmade footprint of the Anthropocene. It goes without saying that, in line with the above, serving the needs of an increasing global population, "*hungry*" for more materials and energy resources, may provide further evidence in favour of the Anthropocene hypothesis. Towards this direction, the global population growth could be perceived as the first milestone of the present study's quest in tracing human footprint in the era of Anthropocene.

3.1.2. The global economic growth in terms of GDP

Economic growth is a fundamental indication of wealth and prosperity at the national and international level. What is more, economic growth indirectly implies the magnitude of the economic system (production of goods and services for the satisfaction of human needs) on the natural system, through the inevitable by-products of the environmental externalities (namely, natural resource depletion and environmental pressure – emissions – pollution). Despite the significant shortcomings, weaknesses and the recent criticism raised by many scientists, Gross Domestic Product (GDP) is still the prevailing indicator for measuring economic growth by the vast majority of national and international bodies, statistics, policy makers, and organisations, while its use remains predominant in international reports, such as those of the World Bank (WB), the International Monetary Fund (IMF), the International Energy Agency (EIA), and the Organisation for Economic Cooperation and Development (OECD), to mention but a few representative examples (Kalimeris *et al.,* 2020).

GDP is measured by summing up a national economy's private expenditures (consumption and investment), public expenditures (government's investment and spending), net exports (the value of the country's exports minus the value of imports) and net capital formation (the increase in value of the economy's total stock of monetized capital goods) (*Ibid*).

A common function of GDP's estimation is presented below (see function 1):

$$GDP_t = C_t + I_t + G_t + (X_t - M_t) \quad (1)$$

Where, C = Consumer spending

I = Investment

G = Government spending

X = Exports

M = Imports

Remarkably, the global GDP has increased almost 14-fold since 1950 (The Conference Board Total Economy Database, 2021), a trend that indirectly incorporates hidden aspects of population growth and enormous increases in resources consumption, infrastructure building, constructions, transportation, and waste-pollution-emissions (Figs. 16a & 16b). To better understand the unprecedented economic growth of the last two centuries, we further estimate the world's regional GDP per capita growth through the historical Maddison Project Database (MPD, 2020). Evidently, after a smooth increase during the mature period of the *Industrial Revolution* era, there is a sheer rapid increase in GDP per capita trends after 1950, the *Great Acceleration* period (Fig. 17).

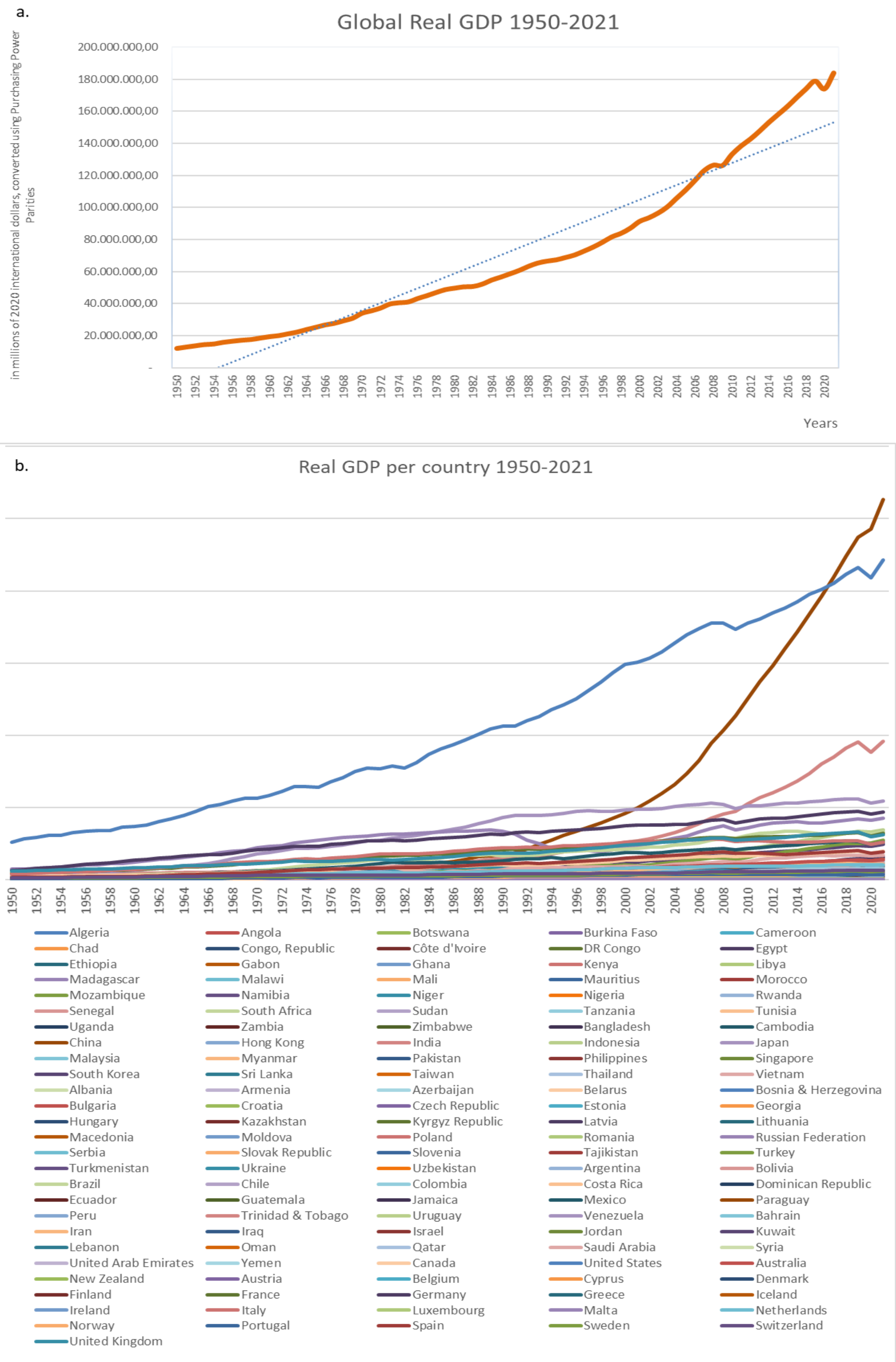


Figure 16. *a. Global Real GDP in 2020 international PPP $ for 1950-2021; and b. Real GDP per country at the global level for 1950-2021. (Data source: The Conference Board Total Economy Database, 2021)*

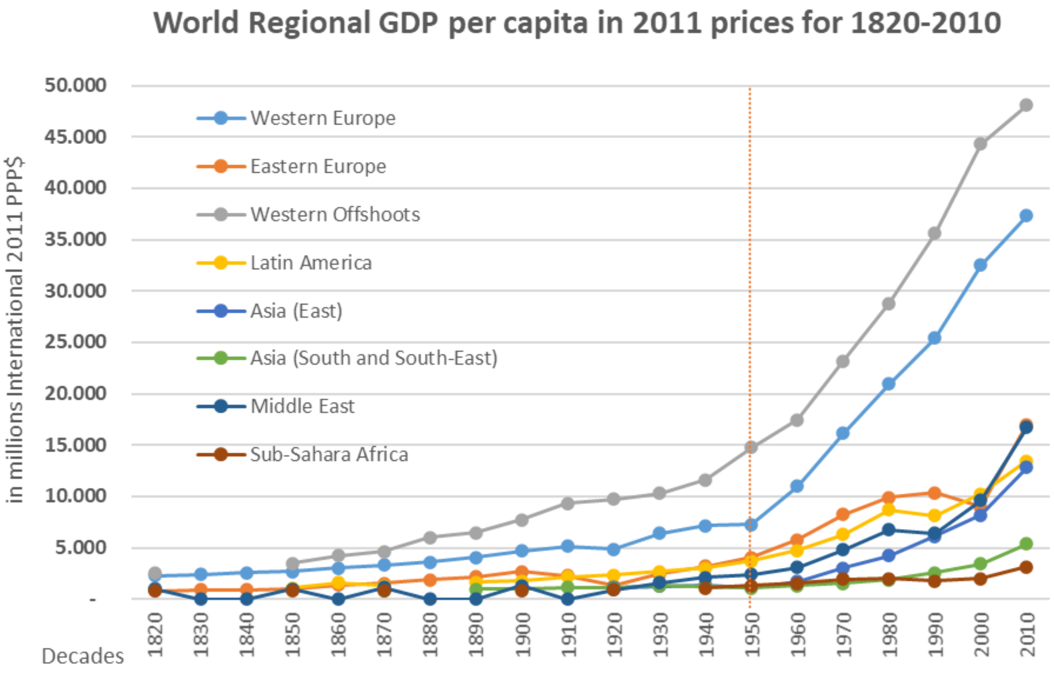


Figure 17. *World regional per capita GDP in 2011 prices, per decade, for 1820-2010 (Data Source: Maddison Project Database, 2020)*

3.1.3. The global energy consumption

According to the Israeli historian Y. Harari (2015 – p. 257) humans were consuming about 13 trillion calories per day in 1500, while today we are consuming more than 1.500 trillion calories per day (thus, 115 times more). Remarkably, while the actual population has increased 14-times from 1500, the goods production and the energy consumption of human societies has increased, since 1500, at 240 and 115 times, respectively. Figure 18 presents the evolution of global primary energy consumption during 1965 – 2020. Indeed, the energy consumption has increased about six times, since 1965 (BP, 2021). Accordingly, Figure 19 presents the percentage (%) contribution of all fuel types to the global primary energy consumption, in 2020. Interestingly, despite the enormous political-societal effort at the global level to alter energy systems towards more renewable resources, fossil fuels (aggregated coal, oil and natural gas) are still contributing (2020), more than 80% of the global primary energy consumption (Fig. 19). These dramatic percentages underline the crucial political, economic, and technical effort required to trigger an effective and viable transformation of the global energy system towards more sustainable alternatives, in the shadow of the ongoing climate changes and escalating environmental degradation threats.

Furthermore, Krausmann *et al.* (2009) provide a long-run database for energy and material consumption at the global level, covering the period of more than a century (1900-2009). This long run perception allows the depiction of the evolution in global energy supply of five (5), crucial for modern human-social systems, energy sources, namely: Coal; Oil; Natural Gas; Biofuels; and hydro – nuclear – geothermal electricity production. In Figure 20, the dot grey line divides the diagram between pre-1950 and after-1950 period. Evidently, the excessive utilization of fossil fuels during the *Great Acceleration* era is remarkably depicted, while the hydro – nuclear – geothermal electricity gradually increases after 1970 (Fig. 20). It goes without saying that the *after-1950* observed evolution in energy supply flows may provide a critical evidence in favour of the 1950 milestone year (or circa 1950), as the initial point, the potential "*golden spike*" of the Anthropocene epoch.

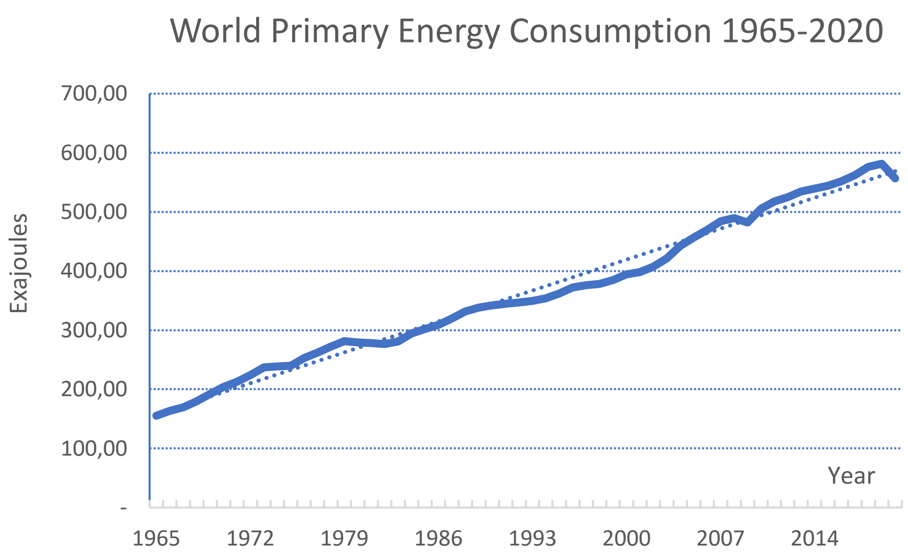


Figure 18. *World's total Primary Energy Consumption during 1965-2020 (Data source: The BP Statistical Review of Energy 2021)*

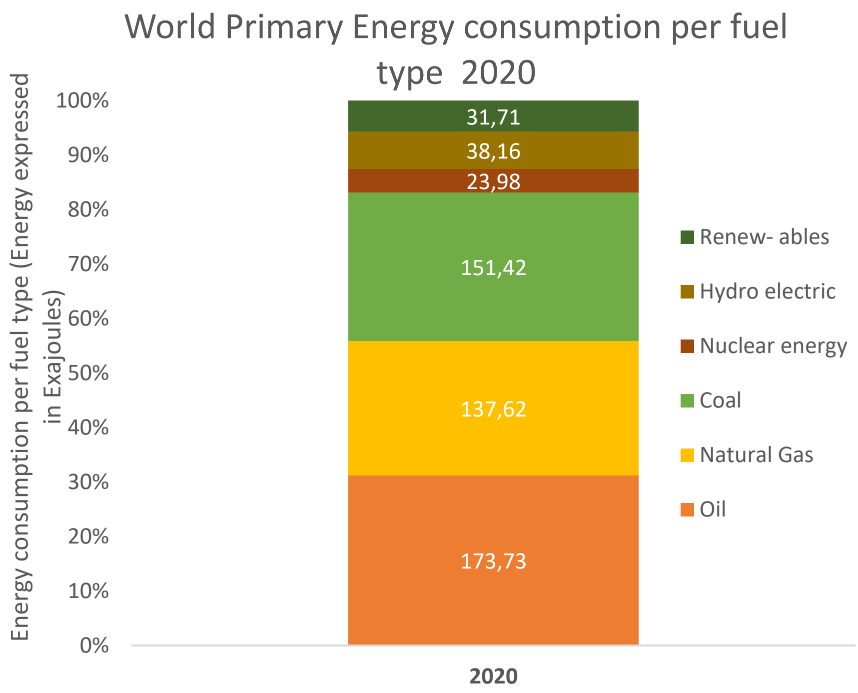


Figure 19. *World's total Primary Energy Consumption per fuel type (%) for 2020 (Data source: The BP Statistical Review of Energy 2021)*

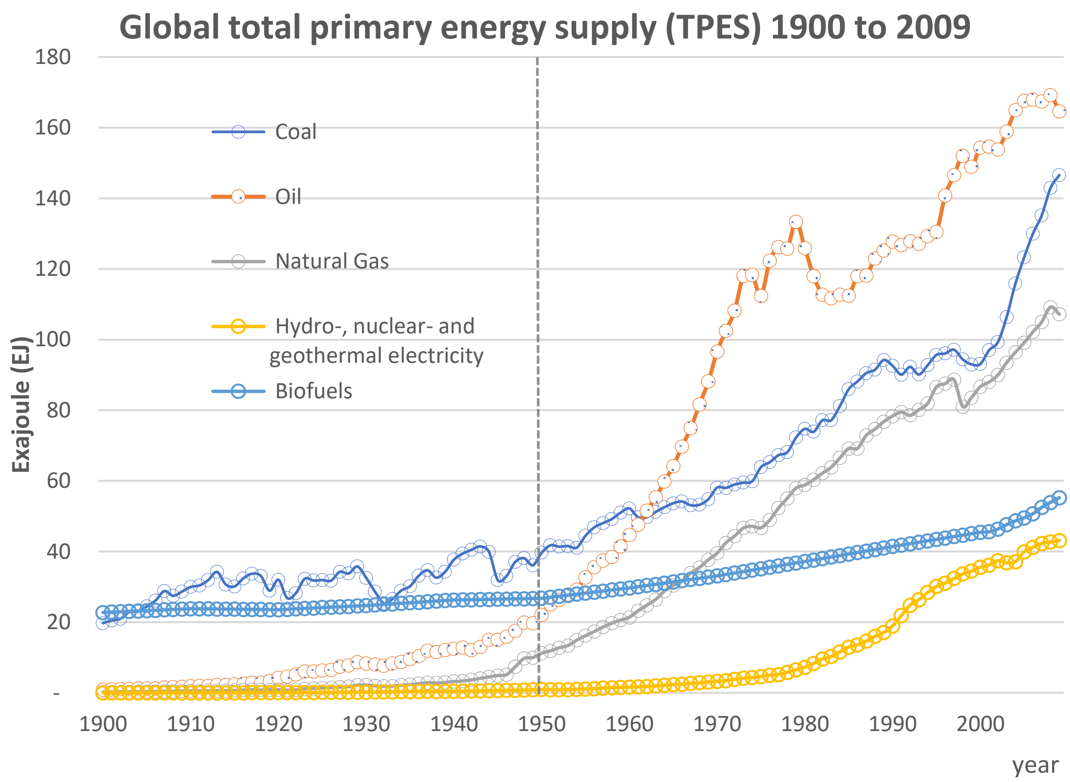


Figure 20. *Global Total Primary Energy Supply (TPES) during 1900-2003. The milestone year 1950, marking the Great Acceleration is highlighted by a vertical grey dotted line. (Data source: Krausmann et al., 2009).*

3.1.4. The global material consumption

Together with *Energy* resources, the *Material* natural resources are remaining essential and vital production factors of modern economy. Material resources, consumed indirectly in the economic process, are the essential mass flows shaping the actual footprint of human societies (the so-called social or industrial metabolism[21]) on Earth. Specifically, material stocks in infrastructure, buildings, products, and machinery are gradually shaping, especially after the *Great Acceleration*, the potential future stratigraphic "*fingerprint*" of homo sapiens.

Evidently, Figure 21 depicts the global flows accumulated during 1950 to 2021, for four (4) indicative aggregate material types, essential trademarks of modern civilization (Wiedenhofer *et al.*, 2021): concrete; asphalt, bricks; steel, copper, aluminium and other metals; plastics, glass, wood and paper. Plastics, as being a critical material for defining potential stratigraphic layers of the Anthropocene in the near future, is examined in more detail in the next paragraph. In a recent study, Plank *et al.* (2022), estimate that, in 2016, 39.7 ±6.1 Gt/year of raw materials were extracted, of which 23% turned into waste during processing. Both raw materials ended up embodied in products and raw materials ended up as waste, eventually will end up their life cycle on the Earth system, as an anthropogenic flow.

Hence, this enormous annually added quantity of manmade materials is already forming the stratigraphic evidence for future studies that will be scrutinizing the Anthropocene hypothesis.

[21] The concepts social or industrial metabolism have been introduced early on by the science of Industrial Ecology. In a nutshell, modern societies consume energy and materials to produce useful goods and services. In that sense, this process can be envisioned as a macrocosmic metabolism taking place within the borders of the entity "society". It is alternatively called industrial metabolism (the entity "Industry" consumes energy-materials to produce useful goods to cover human needs). This metabolism has irrevocably two basic outcome flows: useful goods and useless waste.

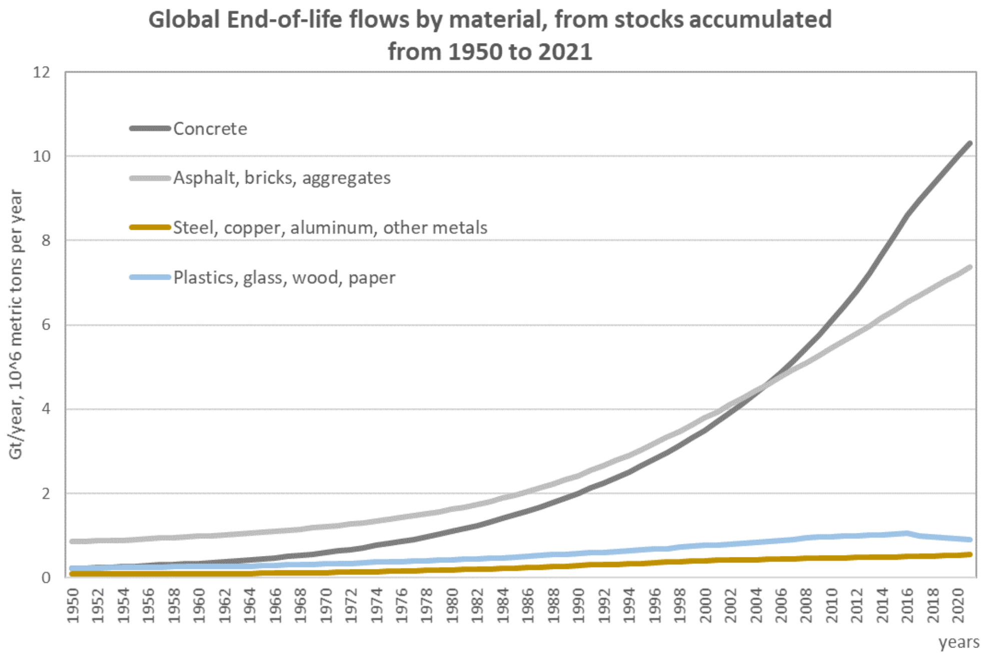


Figure 21 *Stocks accumulated of global EoL flows of various material types after the great acceleration (1950) until 2021 (Figure constructed by the author. Data source: Wiedenhofer et al., 2021)*

By using the on-line tool of material flows net[22], we derived the cartographic synthesis of Figure 22. China's *hunger* for more materials is clearly depicted.

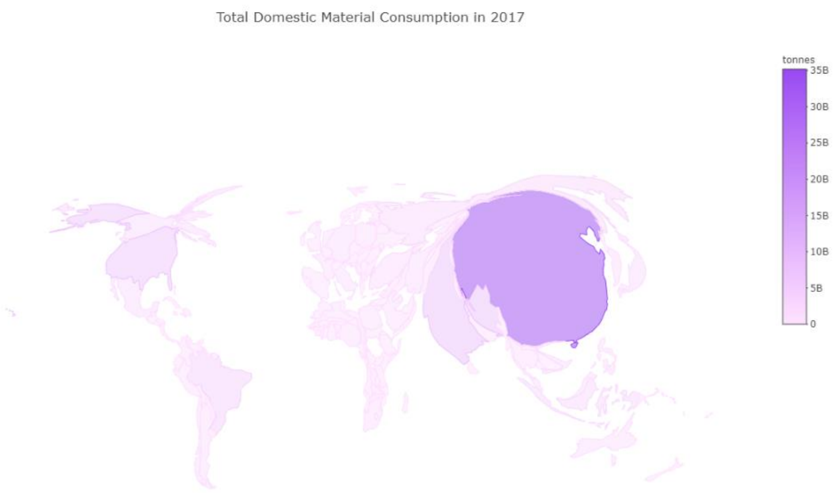


Figure 22. *A cartographic synthesis of global DMC in 2017, the latest year with available data (Source: http://www.materialflows.net/visualisation-centre/)*

[22] Available here: http://www.materialflows.net/visualisation-centre/ (Retrieved in 19.01.2022).

The *Great Acceleration* period is better depicted when long-run datasets are implemented. Krausmann *et al.* (2018) provide estimates for the global in-use stocks and its net additions of Materials for an extensive period of 1900-2015 (Figs. 23a & 23b.). Accordingly, the global material extraction, distinguished into four categories, namely: biomass; fossil energy carriers; ores; non-metallic minerals, is depicted by Figure 24 (Ibid). Again, our analysis reveals the year 1950 as a critical turning point of strong acceleration, for all the examined cases.

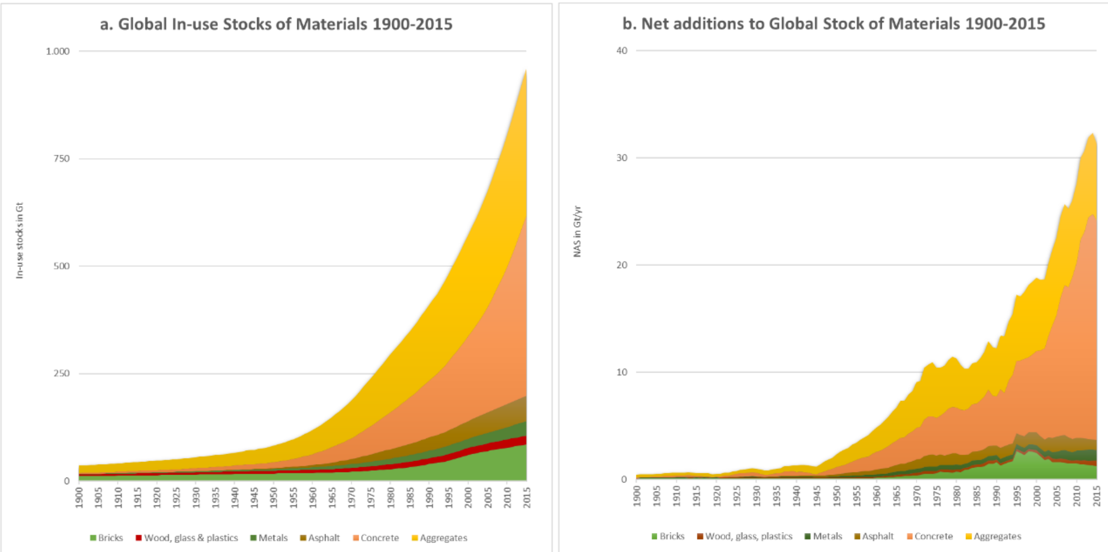


Figure 23. *a) Global in-use stocks of materials; and b)Net additions to global stocks of materials, for 1900-2015 (Data source: Krausmann et al., 2018)*

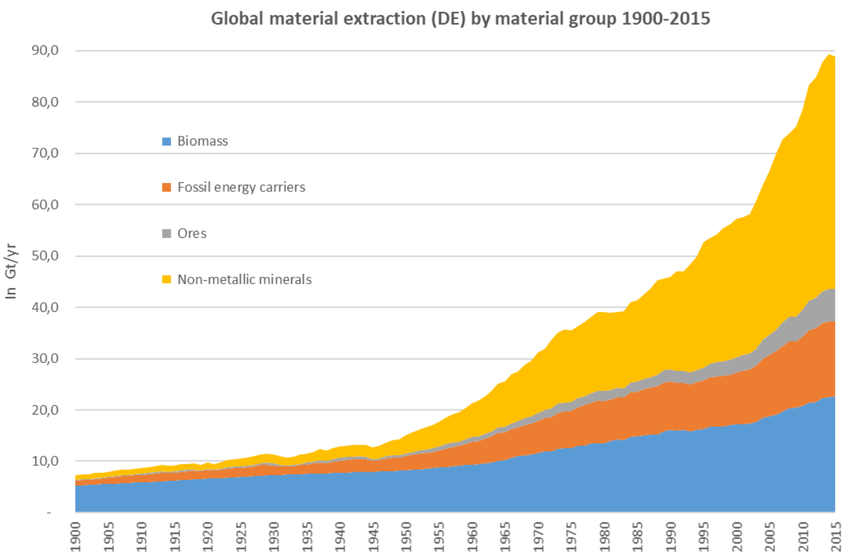


Figure 24. *Global aggregated domestic material extraction per material category, for 1900-2015 (Data source: Krausmann et al., 2018)*

3.1.5. *The global food physical trade balance. Cultivations and food production*

Inevitably, preserving and sustaining an excessively growing global population requires, apart from energy and material resources, enormous quantities of food production. At the same time, this global supply chain of food production and trade requires enormous amounts of energy consumption and results in tremendous changes in land uses, while substantially contributes into more waste - emissions. The strong impacts of this unparalleled food production system may provide additional evidence of the Anthropocene hypothesis. The present subsection focuses on the global food chain's magnitude.

By utilizing data by Krausmann and Langthaler (2019), we have constructed figures presenting the historical trade flows of four main food types, essential for human nutrition: wheat; cereal; meat; and oil crops. Evidently, agricultural production rose from a few million tonnes per year, around 1870, to about 1.4 billion tonnes/yr in 2016 (Ibid).

Global wheat sown area increases constantly from 1878 (≈50,000 ha), until early 1980s (≈240,000 ha), where a stabilization is occurring thereinafter (Fig. 25). Wheat is a critical food ingredient in human nutrition and, apparently, this is clearly depicted in the trends of wheat's global production, which is constantly increasing from 1878 (≈60,000,000 tonnes) to 2016 (750,000,000 tonnes). Remarkably, the turning point of further acceleration in wheat production is the period after the WWII, specifically, after 1950 (Fig. 26).

Another critical nutrient input is cereal, and Fig. 27 presents the global per capita cereal's exports during 1850-2015, which, except for the periods of WWI and WWII, is increasing constantly with an accelerating trend, after 2000.

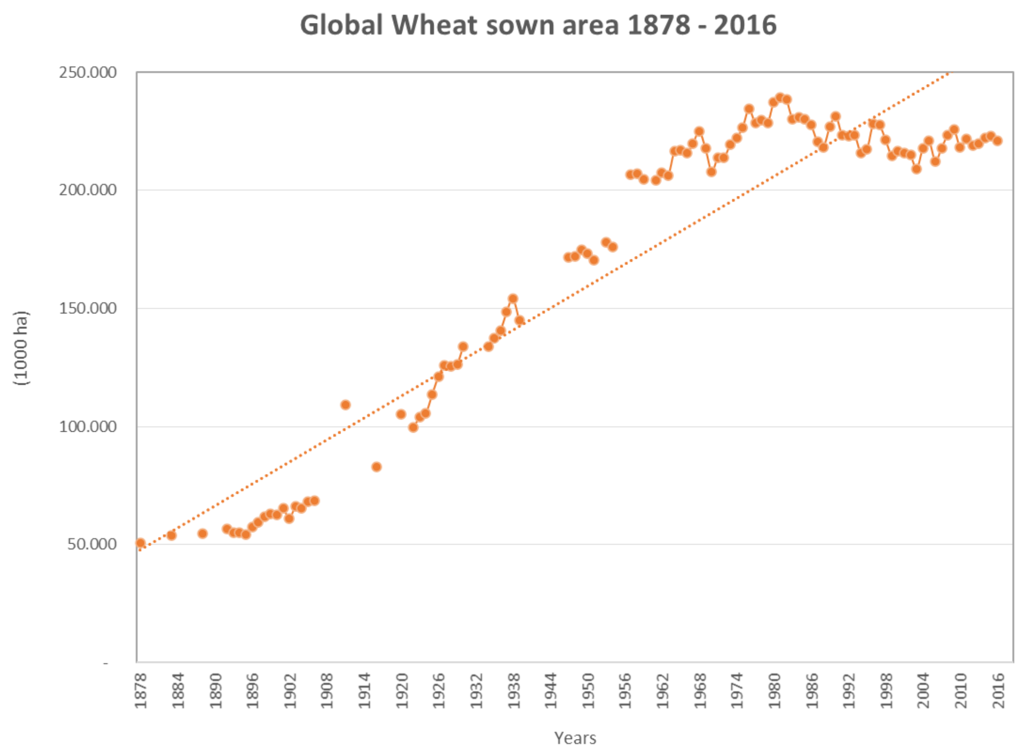


Figure 25. *Global wheat sown area during 1878-2016 (Data source: Krausmann and Langthaler, 2019)*

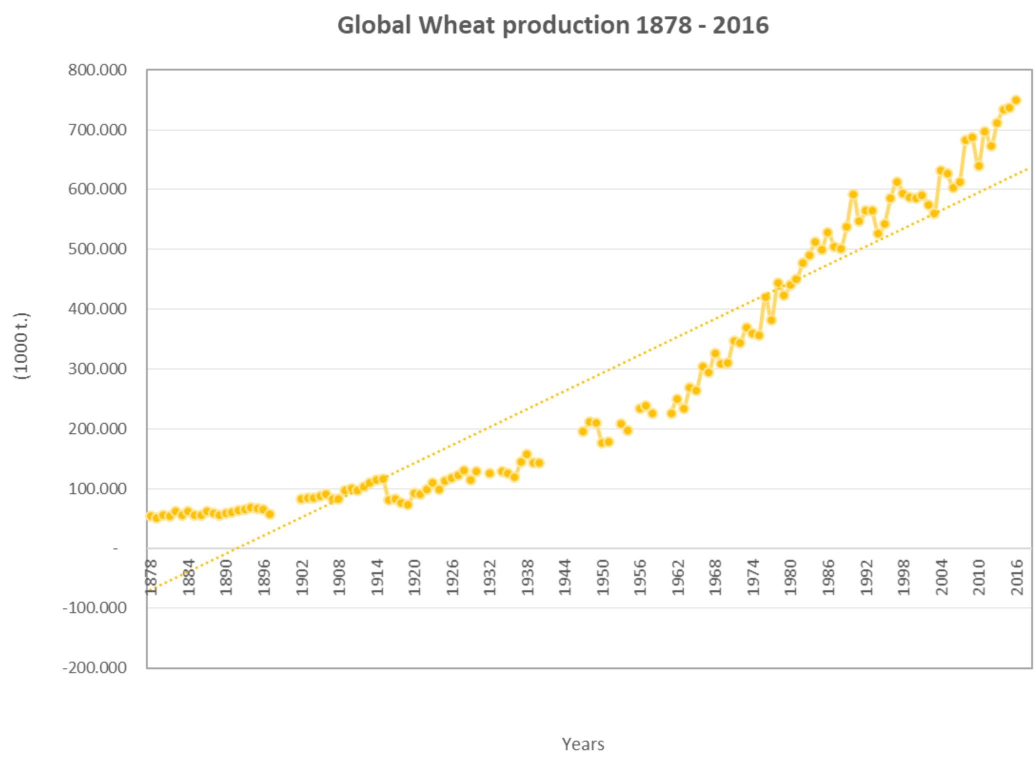


Figure 26. *Global wheat production during 1878-2016 (Data source: Krausmann and Langthaler, 2019)*

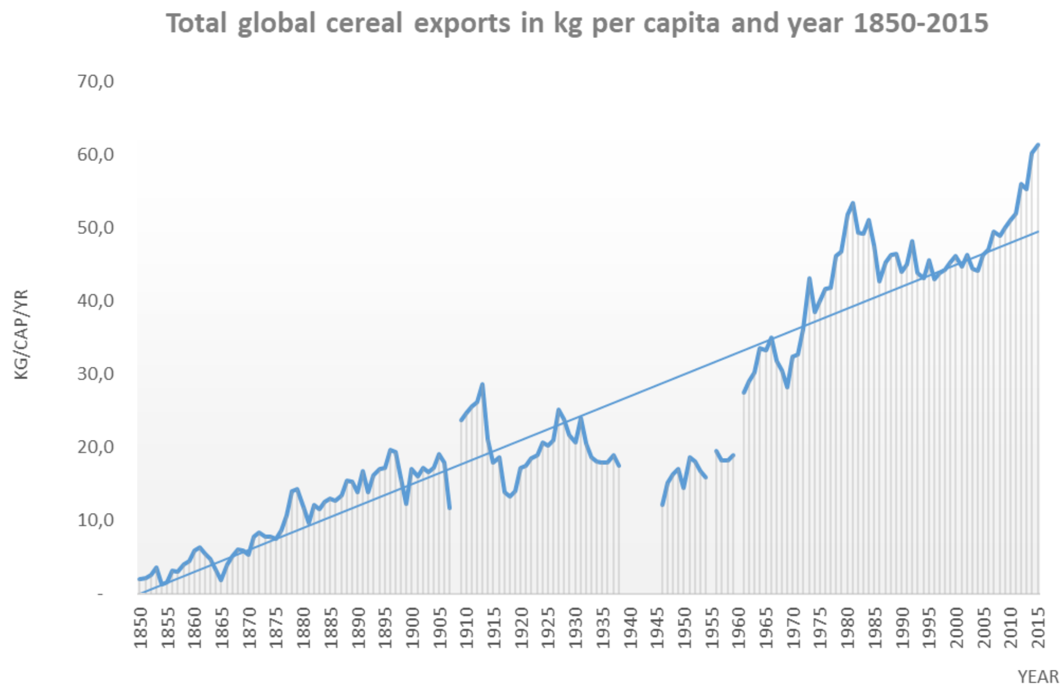


Figure 27. *Global cereal exports expressed in kilograms/person/year during 1850-2015 (Data source: Krausmann and Langthaler, 2019)*

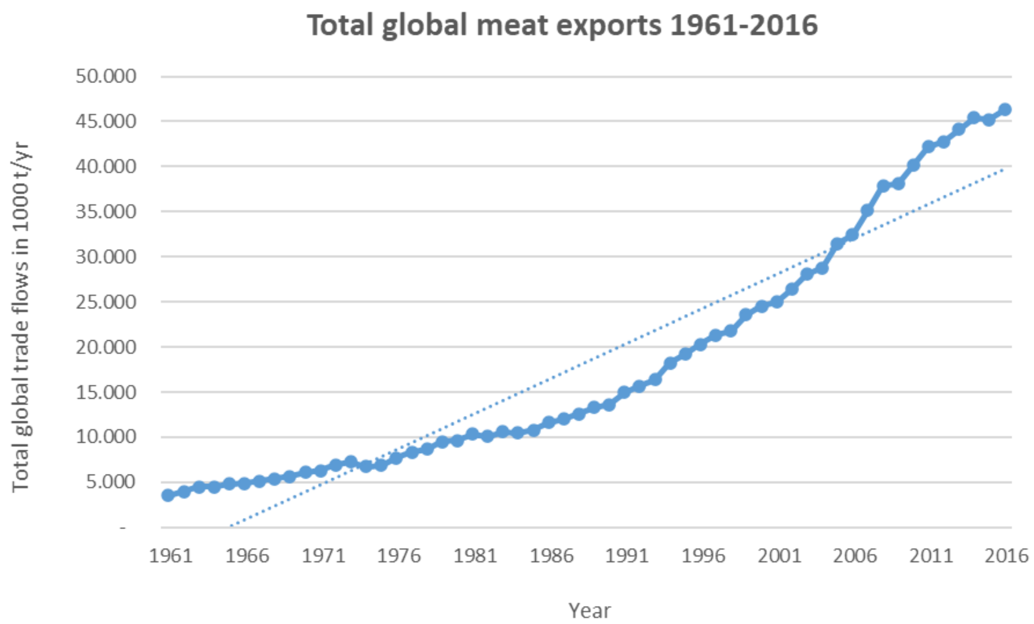


Figure 28. *Global meat exports during 1961-2016 (Data source: Krausmann and Langthaler, 2019)*

Accordingly, Fig. 28 presents the global meat exports during 1961-2016. The meat production industry is highly associated with enormous direct (during the livestock production) and indirect (during the transportation of the final product, worldwide) emissions of greenhouse gases (Nordgren, 2012). Evidently, from the exported 5 million tonnes of meat, in 1961, humanity has reached a 9-fold increase in meat production-trading, namely around 46 million tonnes of meat per year. These numbers are indirectly translated into more and more greenhouse emissions, thus further intensification of climate change's main anthropogenic causes. The previous demographic analysis of global population growth, together with the increasing trends of western lifestyle adaptation by the developing economies of South America, Asia and Africa, probably explains partially the dramatic increment in meat consumption, with no sheer signs of future decline[23].

Additionally, the next Figures 29-31 present the long-run Physical Trade Balance (PTB) of the three, already examined food categories, cereal (1850-2016), meat (1870-2016), and oil crops (1850-2016), respectively. It should be denoted that, since PTB = Imports – Exports, the positive values indicate *net-importer* regions, while negative values indicate *net-exporter* regions. One common feature of all the examined figures is that after the WWII, circa 1950, an acceleration of PTB is depicted for all regions and food categories. Especially, Fig. 30 verifies the previous observations made on the meat consumption trends, as after 1990 the biggest meat net-importers are the regions of Asia, Africa, and Russia/former USSR. What is more, in the cases of cereal and oil crops, the North & Central America and the South America are the biggest net-exporters globally, an evidence of extensive transportation and, hence more indirect emissions, apart from the emissions during the production process of the relevant goods, the land change uses, and so on. In a nutshell, a constantly increasing global population requires more and more nutrients, mainly after 1950, which are not produced locally anymore, but they are transported from many thousand miles away, due to the globalization, the global free market and the world trade network.

[23] While in the west there is an increasing trend of vegetarianism and, more radically, veganism, notwithstanding, many developing economies are constantly increasing their meat consumption to serve the nutrition-caloric needs of their increasing populations.

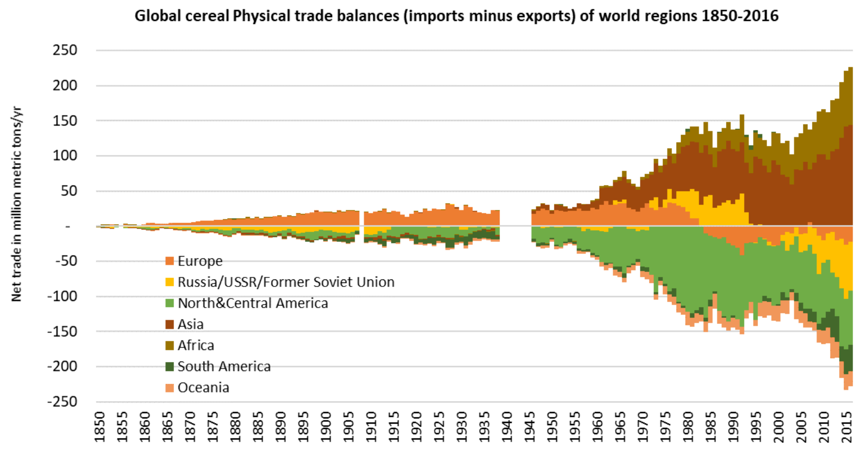


Figure 29. *Global cereal physical trade balances of world's regions during 1850-2016 (Data source: Krausmann and Langthaler, 2019)*

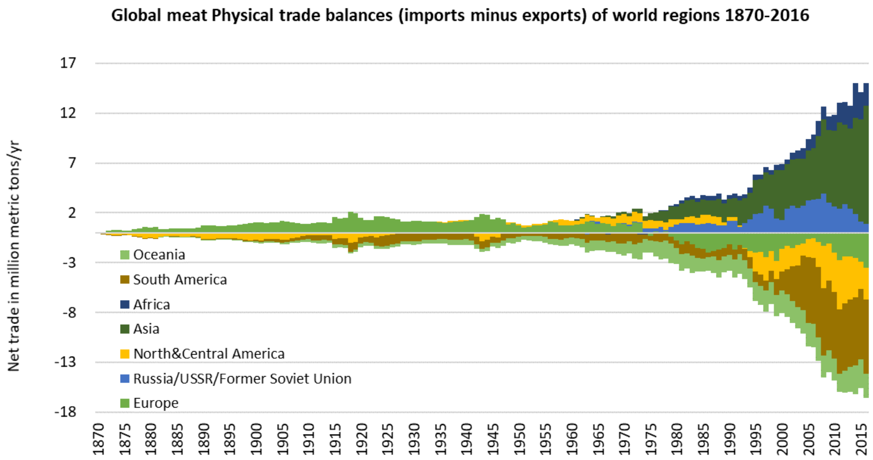


Figure 30. *Global meat physical balances of world's regions during 1870-2016 (Data source: Krausmann and Langthaler, 2019)*

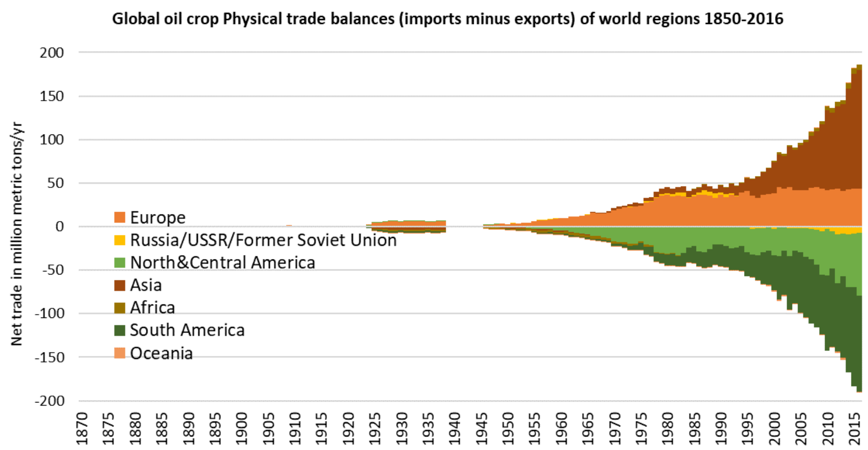


Figure 31. *Global oil crop physical trade balances of world's regions, dusting 1850-2016 (Data source: Krausmann and Langthaler, 2019).*

3.1.6. The global plastics consumption; towards a plastics stratigraphy?

As being a modern manmade material that successfully substituted wood, ceramics and glass in multiple uses, plastics are easy in use and are applicable in numerous everyday uses. While the expansion of plastics use is well known, the actual longevity of plastic polymers in the environment, is yet an open debate (Zalasiewicz *et al.,* 2016). It is assumed that the gradual degradation of plastics may take place chemically, physically, or biologically (Ibid); Nonetheless, the real question is how long it would take until the total degradation. If their degradation proved to be persistent through the long run, then plastic could be still recognizable over geological timescales, thus it serves as a potential stratigraphic layer of the Anthropocene epoch.

We will further discuss in another chapter, the consequences of plastic and microplastic remains in lakes, coastal ecosystems, and the ocean. By using data provided by Wiedenhofer *et al.* (2021), we estimate the global end-of-life (EoL) flows of plastic materials, glass, and paper, accumulated during the *Great Acceleration* period, namely after 1950 until the present (see Figure 32). The aggregate flow of these materials has increased 4-fold, from 200 million metric tonnes in 1950, to more than one billion metric tonnes in 2016.

Figure 33a provides a more detailed insight in the world plastic production, which increased almost 175-fold, from 1.7 Mt in 1950, to more than 299 Mt after 2010. Figure 33b provides evidence of stratigraphic appearance of some major types of plastics. The grey line represents the 1950 milestone, where remarkably, most of the examined plastic materials continuously appear in stratigraphic layers.

Evidently, the aggregate production of plastic materials until 2015 was around 5 billion tonnes, which is enough to plastic wrap the entire planet Earth, while the current global annual production of plastics represents ≈40 kg of plastics per capita, an unprecedented flow of an artificial (manmade) material in the natural system, which triggers scientists to engage new scientific terms, such as the "*plastisphere*" to graphically articulate the magnitude and the dominance of plastic materials on the Biosphere (Zettler *et al.*, 2013; De-la-Torre *et al,* 2021).

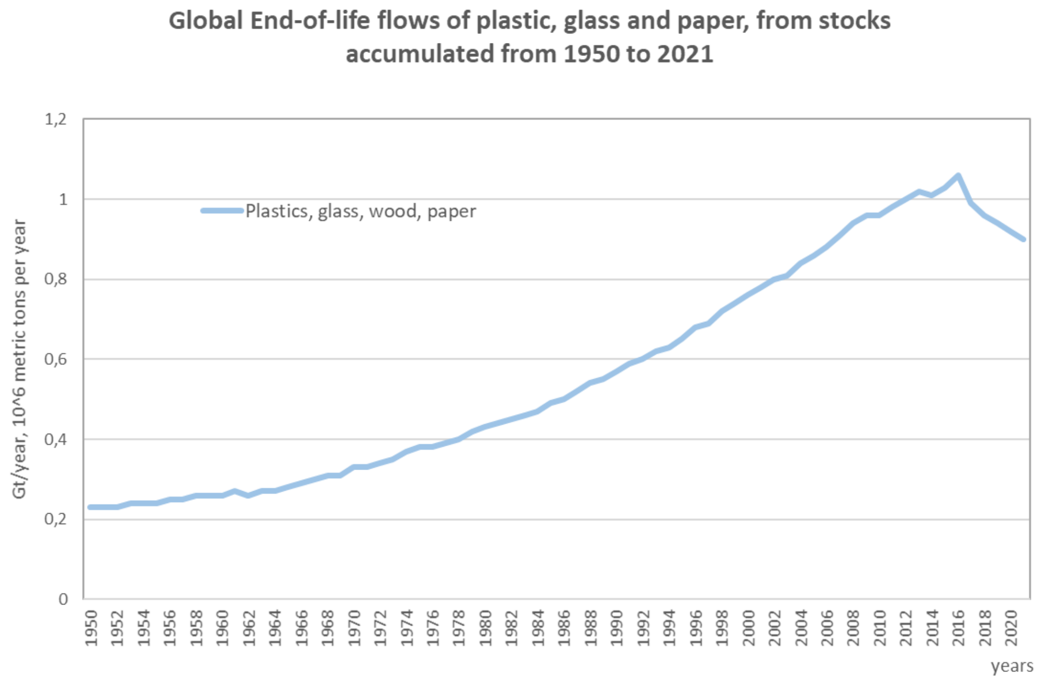


Figure 32 *Global EoL flows of plastic, glass and paper stocks accumulated after the great acceleration (1950) until 2021 (Figure constructed by the author. Data source: Wiedenhofer et al., 2021)*

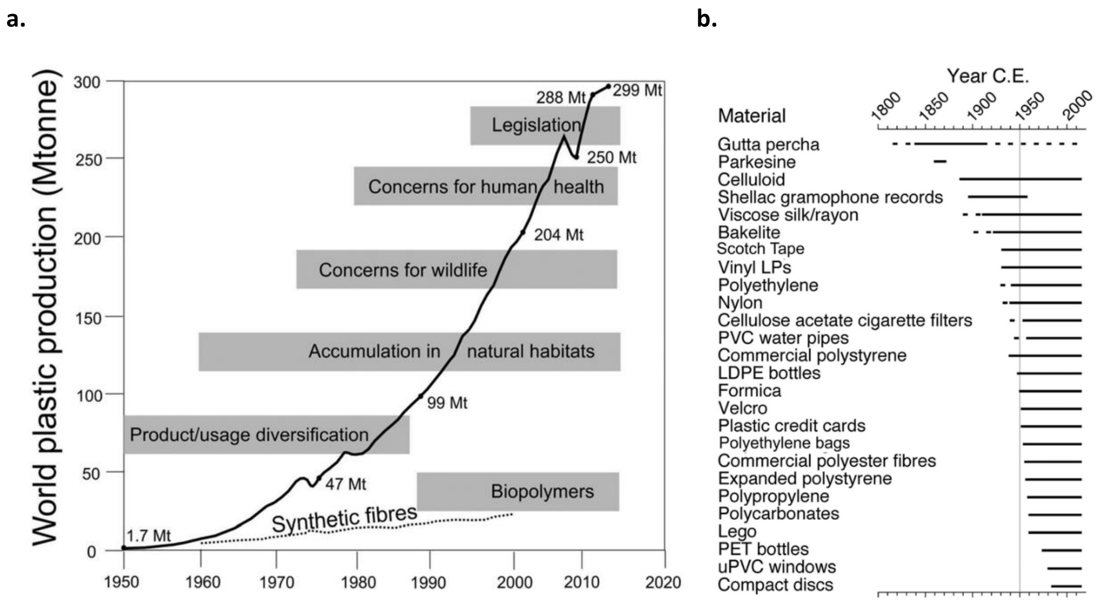


Figure 33 *a. Growth of global plastics production from 1950. The grey boxes provide historical info of the plastics development; and b. analysis per material type (Source: Zalasiewicz* et al.*, 2016 – p. 6. Available at http://nora.nerc.ac.uk/id/eprint/512776/1/Plastic%20stratigraphy%20NORA.pdf)*

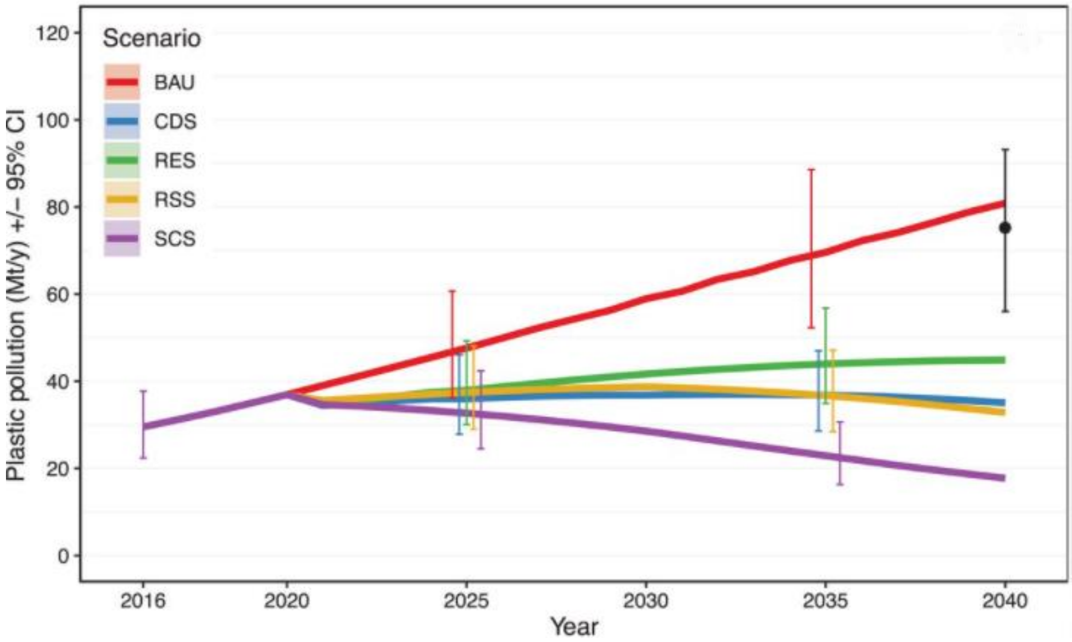


Figure 34. *Time series of plastic pollution in million metric tons/year ± 95%, by scenario, 2016-2040. Scenarios are Business as Usual (BAU), Collect and Dispose scenario (CDS), Recycling scenario (RES), Reduce and Substitute scenario (RSS), and System Change scenario (SCS). Plastic pollution rates for all scenarios between 2016 and 2020 are identical. The black point estimate in 2040 represents the annual rate of plastic pollution if global commitments to reduce plastic use and increase recycling announced before June 2019 are implemented before 2040 (Source: Lau et al., 2020 – p.1456. Available here: https://www.science.org/doi/epdf/10.1126/science.aba9475).*

More recent data reveal that the world plastics production, despite relevant initiatives and policies towards mitigating plastics use in the European Union (EU), is rising continuously; from 359 billion tonnes, in 2018, to 368 billion tonnes, in 2019 (2,5% increase)[24]. More dramatically, a recent publication in the *Science,* by modelling 5 different scenarios, concludes that even with the scenario of increased political and social concern, about 710 million metric tonnes of plastic it is expected to enter the aquatic and terrestrial ecosystems, by 2040 (Lau *et al.,* 2020; EIA, 2022)[25] (See Fig 34). Be that as it may, plastics stratigraphy (together with other manmade techno-fossils) might prove to be in the years to come, one of the strongest stratigraphic evidences

[24] Data are derived by Plastics Europe: https://plasticseurope.org/knowledge-hub/plastics-the-facts-2020/ (Retrieved 13.12.2021)

[25] See Environmental Investigation Agency's (EIA, 2022) report here: https://eia-international.org/wp-content/uploads/2022-EIA-Report-Connecting-the-Dots-SPREADS.pdf (Retrieved 28.01.2022).

of the Anthropocene epoch (See e.g. Gutow and Bergmann, 2017; Elias, 2018; Corcoran *et al.,* 2018).

3.2. The Earth System trends: Tracing Anthropocene's impact on the biosphere

3.2.1. CO_2 emissions and the Climate change

Concentrations of carbon dioxide in the atmosphere have risen from around 260 – 280 (0 ± 10) parts per million (ppm) in the pre-industrial period, circa 1750, (Wigley, 1983; Prentice *et al.,* 2001), to **412.35** ppm in August 2021[26], at the global level (Figure 35).

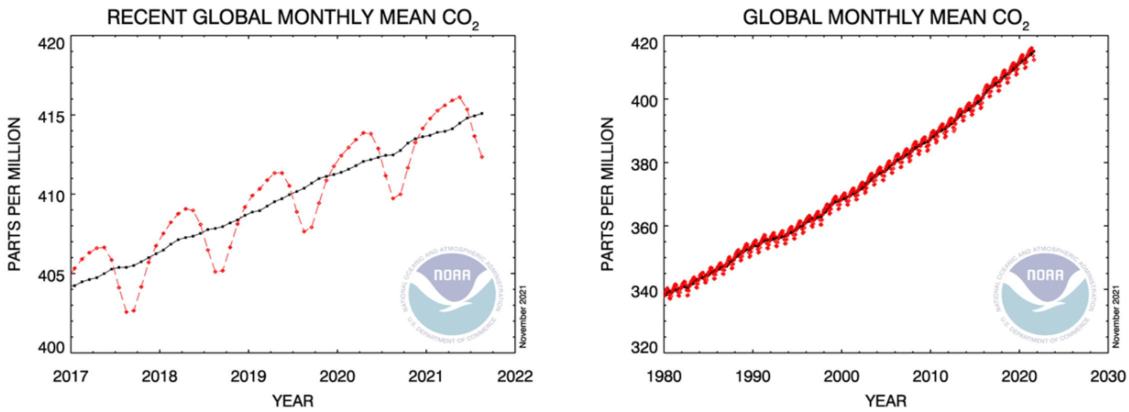


Figure 35 *Monthly mean carbon dioxide globally averaged over marine surface sites. The left figure depicts recent increases from 2017 until late 2021, while the right figure depicts long-run data from 1980 on. (Source: NOAA [27]& [28]).*

Evidently, according to Prentice *et al.,* (2001) the present atmospheric CO_2 concentration has never been exceeded during the past 420,000 years, and probably not during the past 20 million years. The anthropogenic perturbations in the natural

[26] According to the US - National Oceanic & Atmospheric Administration (NOAA): https://gml.noaa.gov/ccgg/trends/global.html (Retrieved 01.12.2021)

[27] left figure: https://gml.noaa.gov/webdata/ccgg/trends/co2_trend_gl.pdf (Retrieved 01.12.2021)

[28] right figure: https://gml.noaa.gov/webdata/ccgg/trends/co2_trend_all_gl.pdf (Retrieved 01.12.2021)

carbon cycle are depicted in Figure 36. Surprisingly, the potential anthropogenic impacts of massive fossil fuels burning were scrutinized in detail with remarkable accuracy, yet under full secrecy, in the early 80s, by the big oil companies (Bonneuil *et al.,* 2021)[29].

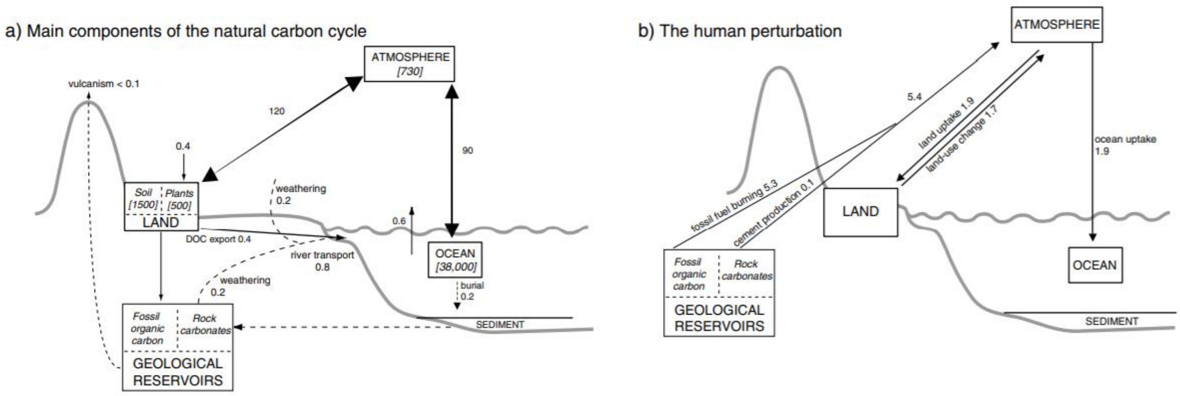


Figure 36. *Comparison of the main components of a) the natural carbon cycle, and b) the human induced contributions (Source: Prentice* et al. *2001 – p. 188).*

The ethical-environmental-legal-economic-social implications/consequences of this delayed information is yet under legal/political/economical investigation. Nonetheless, the fact that from the early '70s the big oil corporations confidentially conducted research on the potential impacts of human activities to the global climate, reveals the magnitude of human footprint on the biosphere, hence advocating in favour of the Anthropocene Hypothesis, especially after the *Great Acceleration golden spike*, where the consumption of fossil fuels increased geometrically (See also § 3.1.2 and 3.1.3 above). The consequences of human induced climate change could be briefly summarized as the increment of hazardous extreme weather events (either floods or

[29] See also the very interesting presentation provided by G. Supran in 21 March 2019: *Hearing of the European Parliament of how communications and secret research about climate change by ExxonMobil and other fossil fuel companies may misled customers, shareholders, and public opinion*: https://www.europarl.europa.eu/cmsdata/162144/Presentation%20Geoffrey%20Supran.pdf (Retrieved in 01.12.2021)

droughts); acceleration of desertification and soil erosion; acceleration in melting of the Greenland and Antarctic ice sheets; sea level rise and increased ocean warming; increase in mortality in coral reefs, and so on, just to mention but a few of the numerous potential hazardous outcomes.

An interesting comparison between the global CO_2 emissions in two different years, namely 1961 and 2020, reveals the huge magnitude of the anthropogenic emissions in a short time period of less than sixty years; evidently, from the 9,418 Million tonnes (Mt) of CO_2 in 1961 (Fig. 37), the emissions has reached 34,807 Mt CO_2 in 2020 (Fig. 38), thus increased more than 3.7 times. Evidently, countries such as China and India, present dramatic differences between the two diagrams, as they are changing their development patterns through time, from underdevelopment rural to highly developing - heavy industrialized countries with increased emissions.

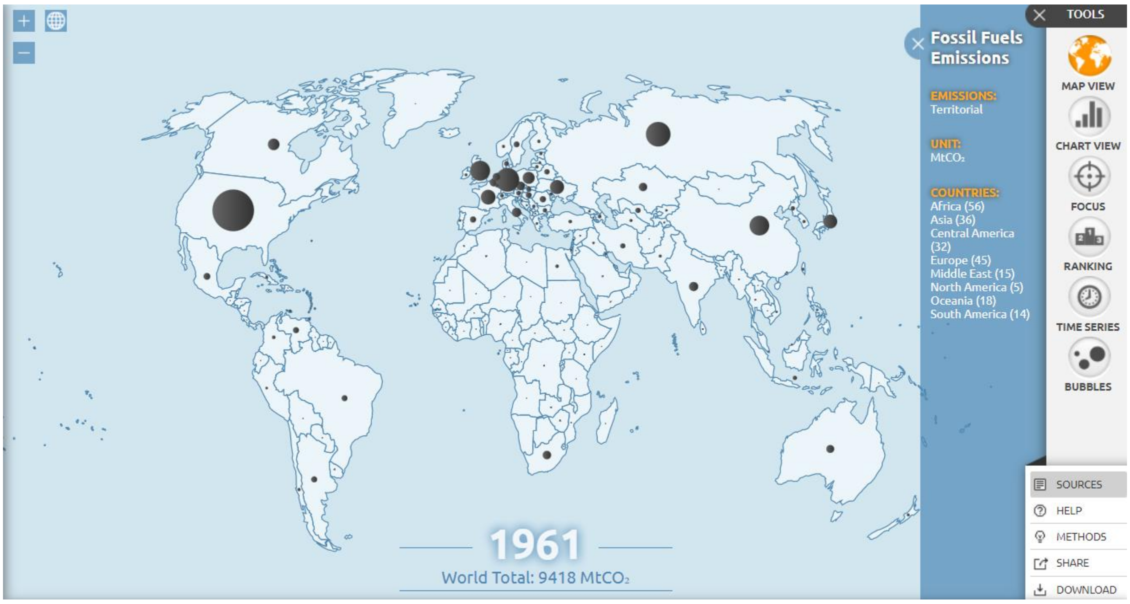


Figure 37. *Global fossil fuels CO_2 emissions per world region in 1961, in Mt. (Data source: Friedlingstein et al. (2021), Andrew and Peters (2021), and Global carbon atlas http://www.globalcarbonatlas.org/en/CO2-emissions.)*

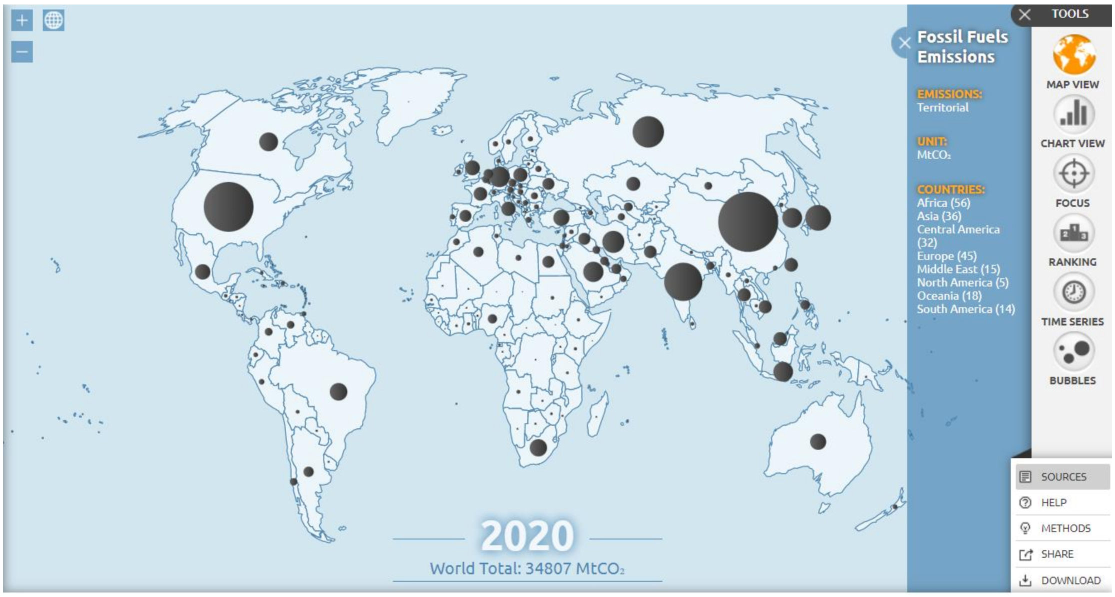


Figure 38. *Global fossil fuels CO_2 emissions per world region in 2020, in Mt. (Data source: Friedlingstein et al. (2021), Andrew and Peters (2021), and Global carbon atlas http://www.globalcarbonatlas.org/en/CO2-emissions.)*

Finally, Fig. 39 presents the ten largest CO_2 emitters, globally, for 2020. Apparently, China has the lion's share with more than 10,668 Mt., whilst the USA is the second world's largest emitter, yet with substantial difference from the first.

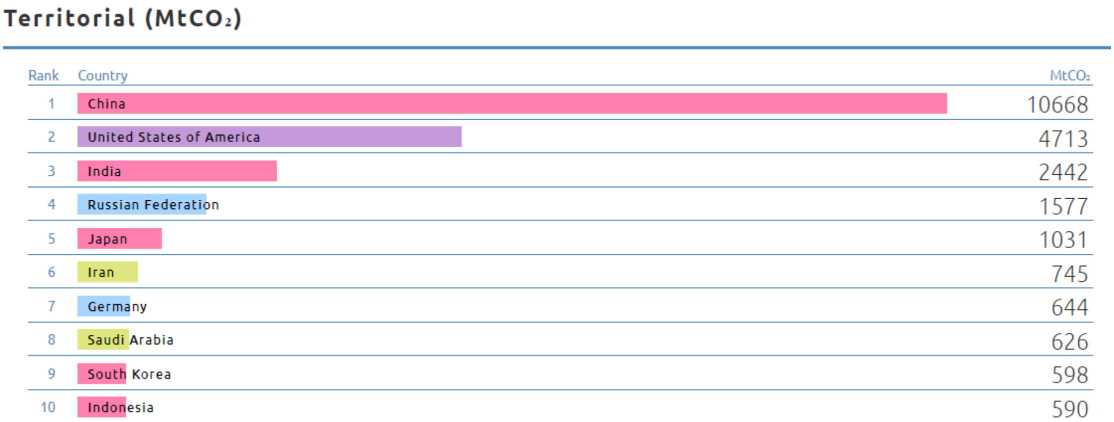


Figure 39. *The ten largest territorial fossil fuels CO_2 emitters of the world, in 2020, in Mt. (Data source: Friedlingstein et al. (2021), Andrew and Peters (2021), and Global carbon atlas http://www.globalcarbonatlas.org/en/CO2-emissions.)*

3.2.2. Stratospheric Ozone layer depletion

The stratospheric Ozone layer functions as a vital filter which protects life on Earth. This asset of Earth system absorbs ultraviolet radiation coming from the sun, which is extremely harmful for humans and other species' lives. While ozone was discovered early in 1839 by German professor Schönbein (Langematz, 2019), it was only in early 1970s when anthropogenic causes recognized as potential threats to ozone layer (Johnston, 1971).

Evidently, it was suggested that the increasing consumption of manmade chlorofluorocarbons (hereinafter CFCs) provides the major source of stratospheric chlorine which might causes depletions of the ozone layer (Molina and Rowland, 1974). Satellite observations and data in the early 1980's verified a declining trend in mid-latitude ozone in the middle and upper stratosphere, by about − 7% per decade (Langematz, 2019). The evidence of this anthropogenic impact on the physical quantity of stratospheric ozone layer increased public concern and inspired immediate political initiatives at the global level, starting with the *Vienna's Convention* for the Protection of the Ozone Layer in 1985 , one of the first conventions that received global acknowledgement and led, finally, into the global legal convergence of *Montreal Protocol* on *Substances that Deplete the Ozone Layer*, in 1987 . The global agreement of the Montreal Protocol, signed by all 196 UN members, and its subsequent amendments and adjustments, resulted in the decreasing of CFCs gases, since the late 1990s.

According to Figure 40, recent projections estimate that a return of global ozone to the 1980 values would be occurred by 2050, while the Antarctic ozone hole is estimated to close after 2060. By all odds, the anthropogenic driven ozone layer depletion underlines the massive power of humans to act as physical agents affecting and destabilizing the Earth system. Perhaps the ozone layer depletion could be perceived as another outcome, with global consequences, of the Anthropocene era. Surprisingly though, maybe it is not a coincidence that Paul Crutzen's main research activity focused on the processes that determine ozone's distribution in the atmosphere.

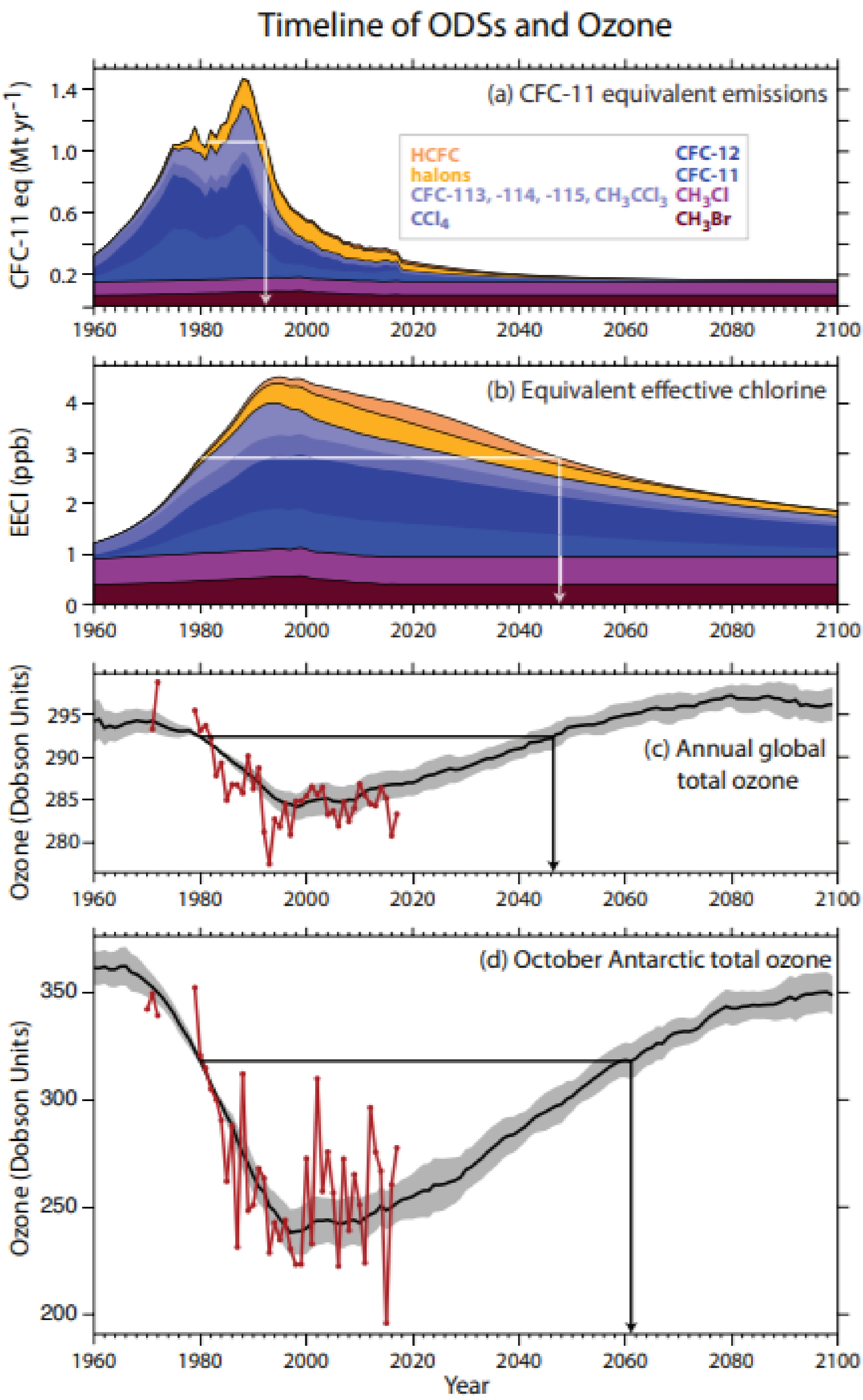


Figure 40. *a). CFC-11-equivalent emissions; b). Equivalent effective chlorine; c). global total ozone; and d). October Antarctic total ozone. (Source WMO, 2018 : [https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf - Retrieved 17.12.2021](https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf))*

3.2.3. Biodiversity loss and the sixth mass extinction era

Human-caused extinctions are taking place at least the last two million years. These prehistoric extinctions were mainly caused by homo species arrival, followed by hunting practices and massive habitat modifications. Today the level of threats for extinction is considered high and many studies anticipate that the rate of extinction may be further increased in the future, suggesting that there will be between 269-350 further extinctions of birds and mammals by the end of the present century, in 2100 (Johnson *et al.,* 2017). In order to capture the dramatic reductions in wildlife populations by human actions, the WWF has established the so-called Living Planet Index, a valuable online tool which estimates the population reduction of mammals, birds, fish, amphibians and reptiles at the global level. According to the most recent estimates, there is taking place an average decline of 68% in wildlife populations, since 1970 (Fig. 41), most of which is occurring in regions with very rich biodiversity such as Latin America & the Caribbean (94%) and Africa (65%) (See Fig. 42).

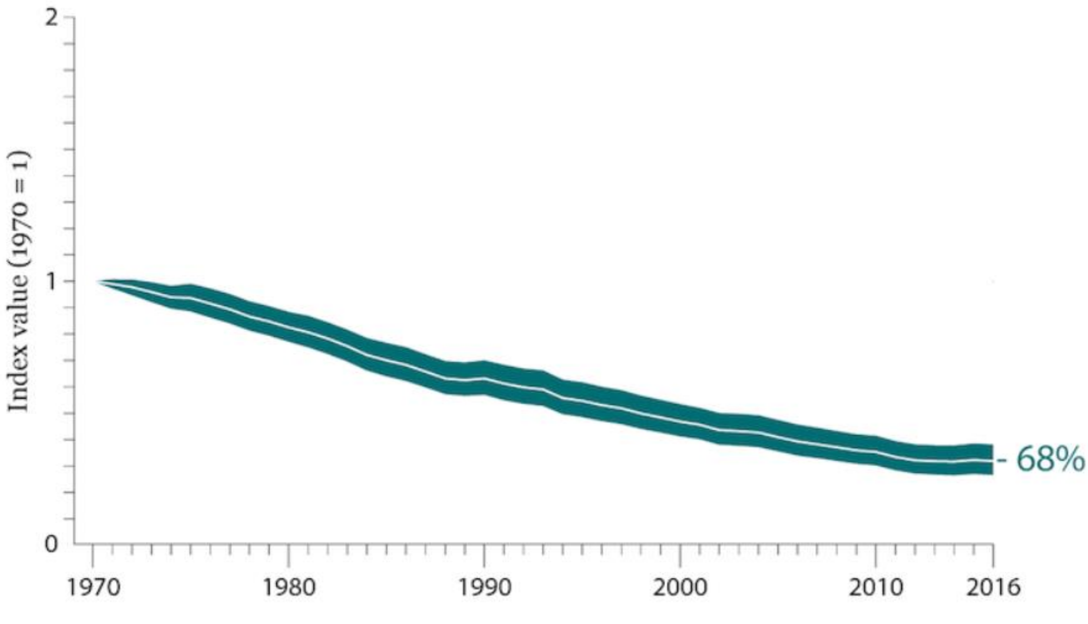


Figure 41. *The Living Planet Index (indexed 1970=1) records a decline of 68% in average population abundance since 1970 (Source: http://stats.livingplanetindex.org/ Retrieved 24.12.2021)*

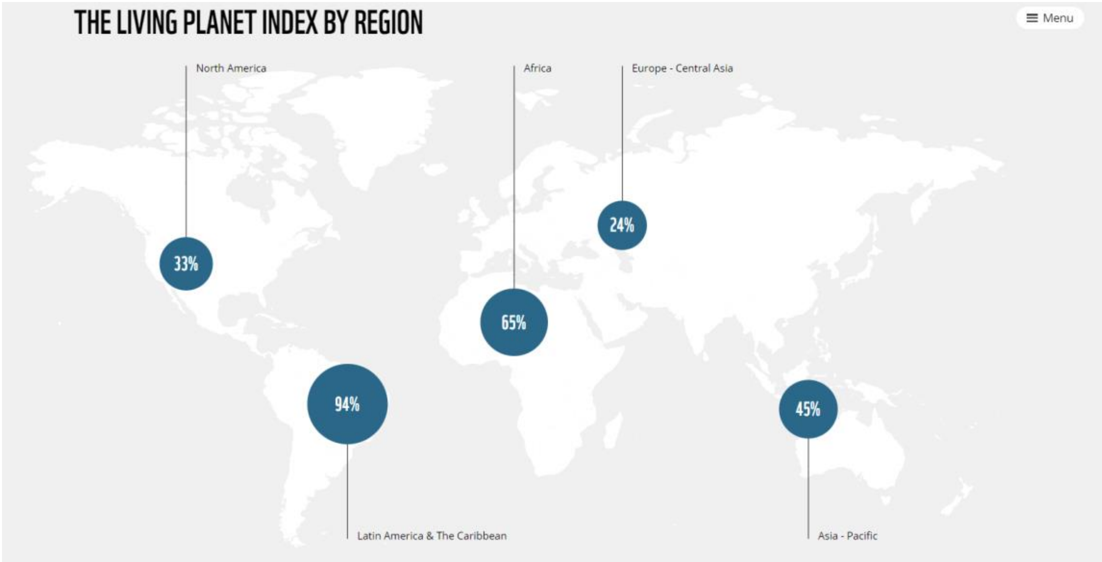


Figure 42. *Estimating the Living Planet Index at the global continental level. (Source: https://livingplanet.panda.org/ Retrieved 24.12.2021)*

More long run empirical investigation reveals that the extinction trends are increasing after the Industrial Revolution, a pattern that turns many researchers to claim that we have entered the 6th Mass Extinction era (Ceballos *et al., 2015*). Evidently, the estimated extinction rates are unprecedented in Earth's history for 65 million years, in terms of magnitude and acceleration in such a short timespan (after 1500 and, especially, after 1800), providing one additional critical turning point denoting the broad impacts of the Anthropocene (ibid - See Figure 43). (See also: Pievani, 2018; Wagler, 2018; Polaina and González-Suárez, 2018).

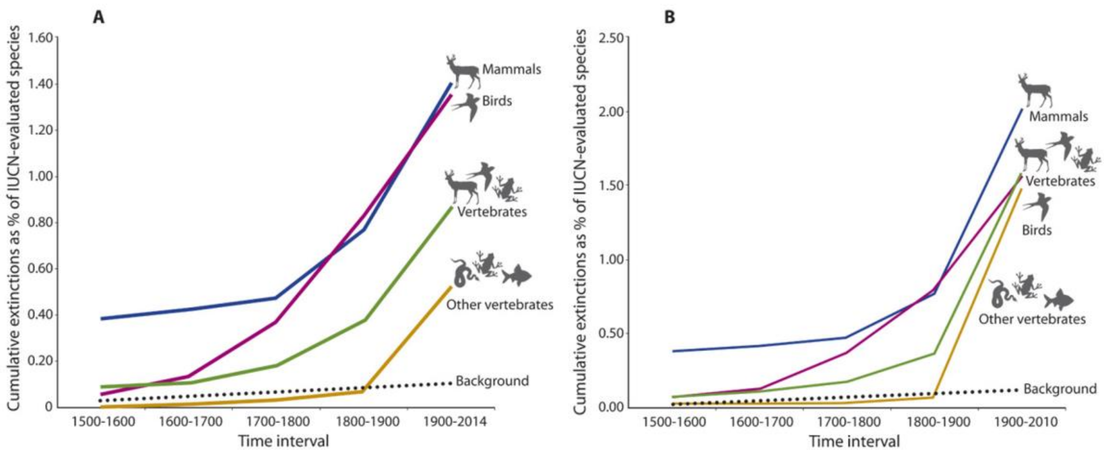


Figure 43 *A). Highly conservative estimate, and B). Conservative estimate. Percentage of the number of species evaluated among mammals, birds, reptiles, amphibians, fishes, and all vertebrates combined.*

The dashed black line represents the number of extinctions expected under a constant standard background rate. (Source: Ceballos et al., 2015).

3.2.4. Eustatic sea level rise (ESLR)

The rate of the global eustatic sea level rise is estimated to be three (3) times faster than it was for the past several thousand years and is comparable to values associated with the mid- Holocene period, while this observation may be attributed to human-induced global warming through climate changes (Medeer and Parkinson*,* 2018). A recent study estimates that the rates of sea-level rise emerged above pre-industrial rates by 1863, yet it seems that different emergence patterns are revealed for the earlier mid- Atlantic area (circa 1872–1894), and Canada and Europe (circa 1930–1964) (Walker *et al.,* 2022). What is more, new evidence brings forward the dominance of glaciers melting contribution to the eustatic sea level rise (ESLR)[30], during the 21st century. It is expected that glaciers meltdown could contribute to an additional sea level rise of 0.1 to 0.25 meter by 2100, apart from ocean warming and the two ice sheets ice lost (the Antarctic and the Greenland ice sheets)[31], due to human-induced climate changes (Meier *et al.,* 2007).

Overall, the global sea-level mean is projected to rise about a metre by the end of the century, by 2100, and this occurrence is expected to have unprecedentedly severe impacts on the most vulnerable coastal areas, such as coastal ecosystems, islands archipelagos, heavily populated urban-coastal areas around the globe, and thus will further deteriorate water supply of these already stressed lands (Stocker *et al.*, 2014). Early studies estimate that only the eustatic sea-level rise could result in the loss of 22% of the world's coastal wetlands by 2080 and, if that trend combined with

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[30] According to Rovere *et al.* (2016), *"…eustatic sea level changes are driven by different processes that cause changes in the volume or mass of the world ocean and result in globally uniform mean sea level variations [..] therefore, are independent from local factors, such as tectonics moving a coastal area upwards…"*

[31] For the two major ice sheets of the world see also: The National Geographic Society: https://www.nationalgeographic.org/encyclopedia/ice-sheet/ (Retrieved 26.12.2021).

additional human activities on wetlands, losses could reach even the dramatic 70% (Nicholls *et al.,* 1999).

Notwithstanding, it worth mentioned here that these projections on the sea level rise are characterized by high uncertainty due to the fact that there is yet a poor understanding of the sensitivity of ice sheets in sustained warming, as well as the observed temporal sea level variability, in such a short, in terms of geology, centennial period of time (Hallmann *et al.,* 2018). By all odds, population density and urbanization of coastal areas and islands call for a better understanding of the threats may occurred by the potential global mean sea level rise, as an outcome of the anthropogenic pressures on Earth's climate.

3.2.5. Ocean acidification

Geological or geochemical proxy evidence for	Future & "Anthropocene"	Deglacial Transition	Oligocene – Pliocene	PETM	End Cretaceous	OAEs	Triassic/ Jurassic	Permian/ Triassic
pCO_2 change	↑	↑	⇡	↑	↑	↑	↑	⇡
pH change	↓	↓	⇣	⇣	?	?	?	?
Saturation Change	↓	↓	–	↓	↓	?	?	?
Temperature Change	↑	↑	↑	↑	⇡	↑	⇡	⇡
Carbon Release		X	X					
Ocean Acidification Score	/3	2	1	3	1	1.5	2	1.5

Table 6. *Review of geological events with increasing CO_2 input in oceans and potential impacts on the oceanic pH. In terms of oceanic acidification score, the Paleocene-Eocene Thermal Maximum (PETM) period seems to have closer relationship to the present. (Source: Supporting Material provided by Hönisch et al., 2012 – page 8).*

A part of the excessive CO_2 emitted into the atmosphere by human activities, is absorbed by the oceans. This enormous quantity of the oceanic CO_2 is expected to decrease in the long run the oceanic pH, thus increase the acidity of oceans, with potential dramatic consequences for marine species, marine biodiversity and, thus, degradation of the oceanic ecosystem services. This anthropogenic oceanic alteration may reveal the enormous power of humans acting as geological agents, showcasing more evidence of the Anthropocene era. Towards this direction, a critical study published in the prestigious *Science* magazine by Hönisch *et al*. (2012), reviews the geological events that potentially affected the oceanic pH, from the last deglaciation to the largest mass extinction in Earth's history.

Evidently, the current rate of anthropogenic CO_2 addition to the oceans is much faster than at any geological event occurred in the past, according to the relevant data (*Ibid*). Nonetheless, it remains obscured what might possibly occur to the future oceanic pH (See Table 6), whilst others argue that the multiple complexity of the present human-induced impacts on the oceanic system may not be analogues to paleo-geological similar events, thus comparisons may be made under high uncertainty (Doney *et al.*, 2009). Despite this uncertainty, there are studies anticipating potential damage by oceanic pH decrement in the entire oceanic ecosystem: from calcifying macroalgae, cold water corals and fishery stocks, to phytoplankton and seagrasses, these changes might have irrevocable and yet unknown impacts to the entire oceanic ecosystem, altering conditions with potential dramatic results in natural geochemical cycles and marine life as we know it (Guinotte and Fabry, 2008; Guo *et al.,* 2020).

3.2.6. Atlantic Meridional Overturning Circulation disturbances

The Atlantic Meridional Overturning Circulation (hereinafter AMOC), is a complex system consisted by ocean currents[32] that circulates warm waters, from the tropics, northwards to the North Atlantic Ocean, towards subpolar and Arctic regions, and again southwards. The main driving forces of these ocean currents are differences in

[32] For more about ocean currents term, see also: https://www.nationalgeographic.org/topics/resource-library-ocean-currents/?q=&page=1&per_page=25 (Retrieved 14.12.2021)

the water's density, namely, in the temperature and the salinity of the sea water. In a nutshell, as the tropical warm water flows to the north it cools while some quantity evaporates. This evaporation increases the salinity of the water which, together with lower temperature, makes the water denser, thus heavier, consequently it sinks deep into the ocean. This denser water streams again southwards, a few kilometres below the ocean's surface. Eventually, it gets upwelled back to the surface and warms again, through a process known as "*upwelling*[33]" and the circulation starts again[34]. The impact of the human-induced climate change and the consequent global warming on this natural circulation system is yet an open debate[35]. However, recent empirical studies are signalling alarming findings that global warming may results in slowing down AMOC during the 20th century (Drijfhout *et al.* 2012; Caesar *et al.,* 2018; Neto *et al.,* 2021; Boers, 2021). Towards this direction, it is expected that continuous global warming is most likely to further slowdown the AMOC through potential forthcoming changes to the hydrological cycle, the sea-ice loss of glaciers and the accelerated melting of the Greenland Ice Sheet, causing further additions of fresh water to the northern Atlantic (Bakker *et al.,* 2016).

Furthermore, the weakening of AMOC may already affects the weather in Europe, as cold weather in the subpolar Atlantic Ocean correlates with high summer temperatures over Europe e.g. the heat wave that Europe experienced in 2015 has been linked to the strong cold record occurred over the same year in the Atlantic (Duchez *et al.,* 2016). Given the fact that the east coastline of north America and the northwest parts of Europe is an overpopulated area gathering crucial socio-economic activity, a potential collapse of AMOC, from the current status to a weaker circulation mode could have critical impacts on the global climate system and unpredictable implications to the global economic-societal system (Boers, 2021; Caesar *et al.,* 2018). In that sense, even though there is no direct stratigraphic evidence of these severe,

[33] Upwelling phenomenon is described here: https://oceanservice.noaa.gov/facts/upwelling.html (Retrieved 14.12.2021)

[34] More details of the AMOC process here: https://www.metoffice.gov.uk/weather/learn-about/weather/oceans/amoc (Retrieved 14.12.2021)

[35] See also: https://www.oceanographicmagazine.com/news/amoc/ (Retrieved 14.12.2021)

anthropogenic to some extent, impacts, the fact that human actions may potentially jeopardize the stability of one of the largest climate regulatory mechanisms on the Earth system, adds more evidence in favour of the Anthropocene's hypothesis.

3.2.7. Planetary Boundaries; an epilogue

The novel conception of the *Planetary Boundaries* (PB) framework, promoted by the *Resilience Institute of the University of Stockholm*[36], provides one of the most holistic, integrated, and multidisciplinary quantified overviews of human impacts on the biosphere. The main idea behind the framework is to identify and quantify nine (9) fundamental processes that regulate the stability and resilience of the entire Earth system, and to define whether these processes are currently functioning within the respective natural boundaries, or not (Steffen *et al.*, 2015):

1. **Climate Change** (Control variable: CO_2 – zone of uncertainty: 350-450 ppm)
2. **Biosphere Integrity** (Control variable: Extinction rate)
3. **Stratospheric Ozone layer** (Control variable: O_3)
4. **Ocean Acidification** (Control variable: aragonite saturation state)
5. **Biochemical flows** (Control variable: P and N cycles)
6. **Land-System Change** (Control variable: % change of forest cover)
7. **Freshwater use** (Control variable: blue water[37] use)
8. **Atmospheric aerosol loading** (Control variable: Aerosol Optical Depth - AOD)
9. **Novel Entities**[38] (Control variables: various manmade staff: e.g. from toxic and radioactive materials, genetically modified organisms, nanomaterials, and micro-plastics).

[36] Indeed, the Resilience Institute has established a specialized research panel under the name "*Anthropocene dynamics*", focusing to understand and support the human capacity in the era of Anthropocene. For more: https://www.stockholmresilience.org/research/planetary-boundaries.html (Retrieved 10.02.2022).

[37] More about water categorizations here: https://waterfootprint.org/en/water-footprint/what-is-water-footprint/ (Retrieved 10.02.2022)

[38] More about novel entities, Anthropocene and Planetary Boundaries here: https://www.anthropocene.info/pb2.php (Retrieved 10.02.2022)

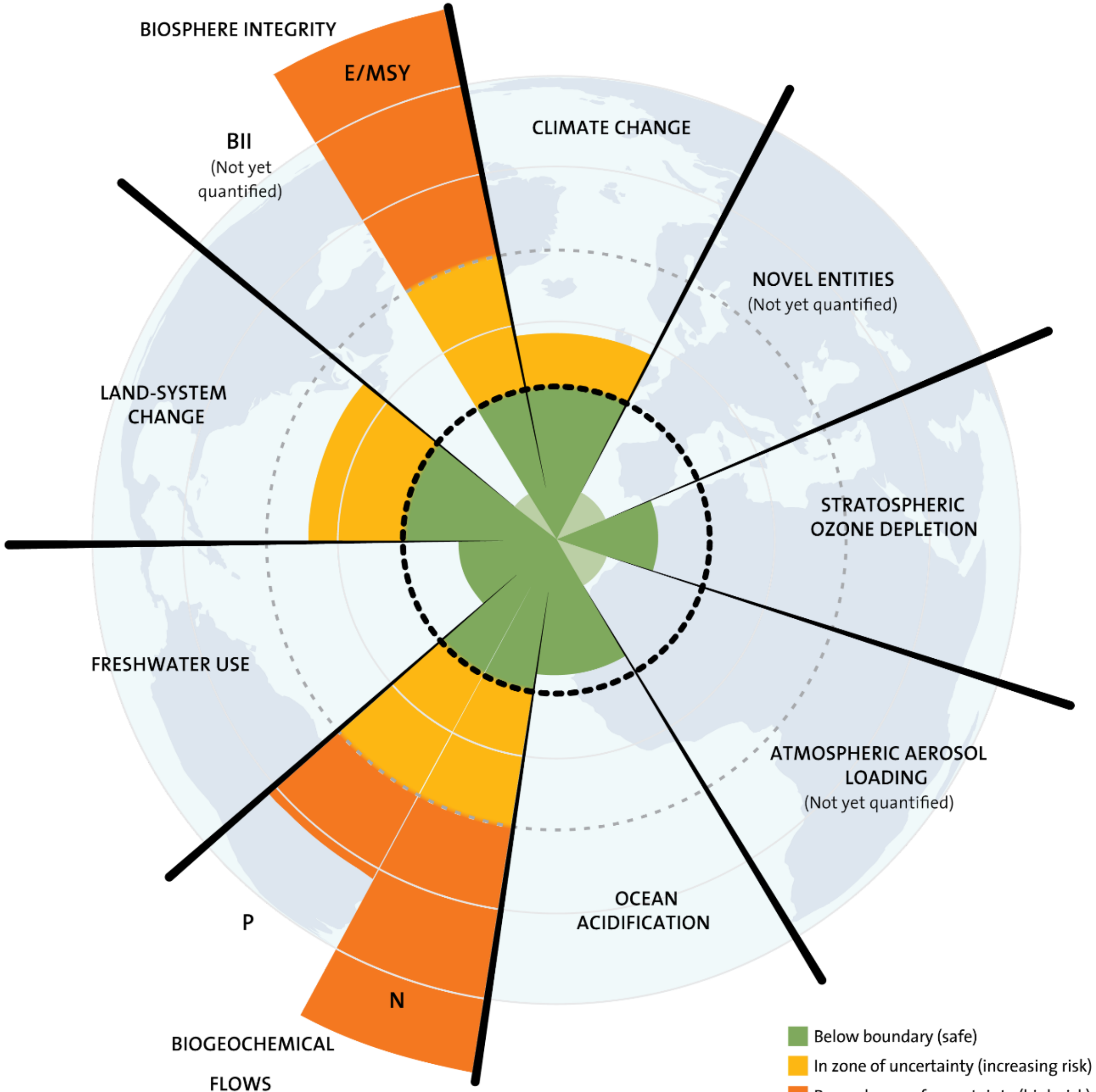
These nine regulating processes - flows are of paramount importance for the preservation of the minimum safe operation standards and the biological crucial levels that are essential for the preservation of human life on Earth (See Figures in Annexes I & II of the 3rd Chapter). Any violation of these boundaries (the safe operating space is denoted in green colour in Annexes I & II) by human-induced actions is a signal of disturbance and destabilization of the natural system, compromising the life quality of human beings with potential negative impact on their health and, thus, their well-being and prosperity.

Annex I of the 3rd Chapter presents the status of PB in 2015, where two processes (namely, biochemical flows and, partially, biosphere integrity) are quantified as *beyond the zone of uncertainty* (translated into "*high risk*"), while two others (climate change and land system change) are at the *zone of uncertainty*, thus into "*increasing risk*".

A recent update of PB (Persson *et al.*, 2022) introduces the quantification of various novel entities, adding a third boundary functioning beyond the zone of uncertainty (See Annex II – 3rd Chapter). Remarkably, five out of nine PB are functioning between the zone of uncertainty and beyond the zone of uncertainty, while ocean's acidification is approaching the upper limit of the safe operation space. Apparently, the biosphere is characterized by a sheer imbalance in terms of the PB concept, a trend which is expected to further deteriorate once other pending categories properly quantified in the future.

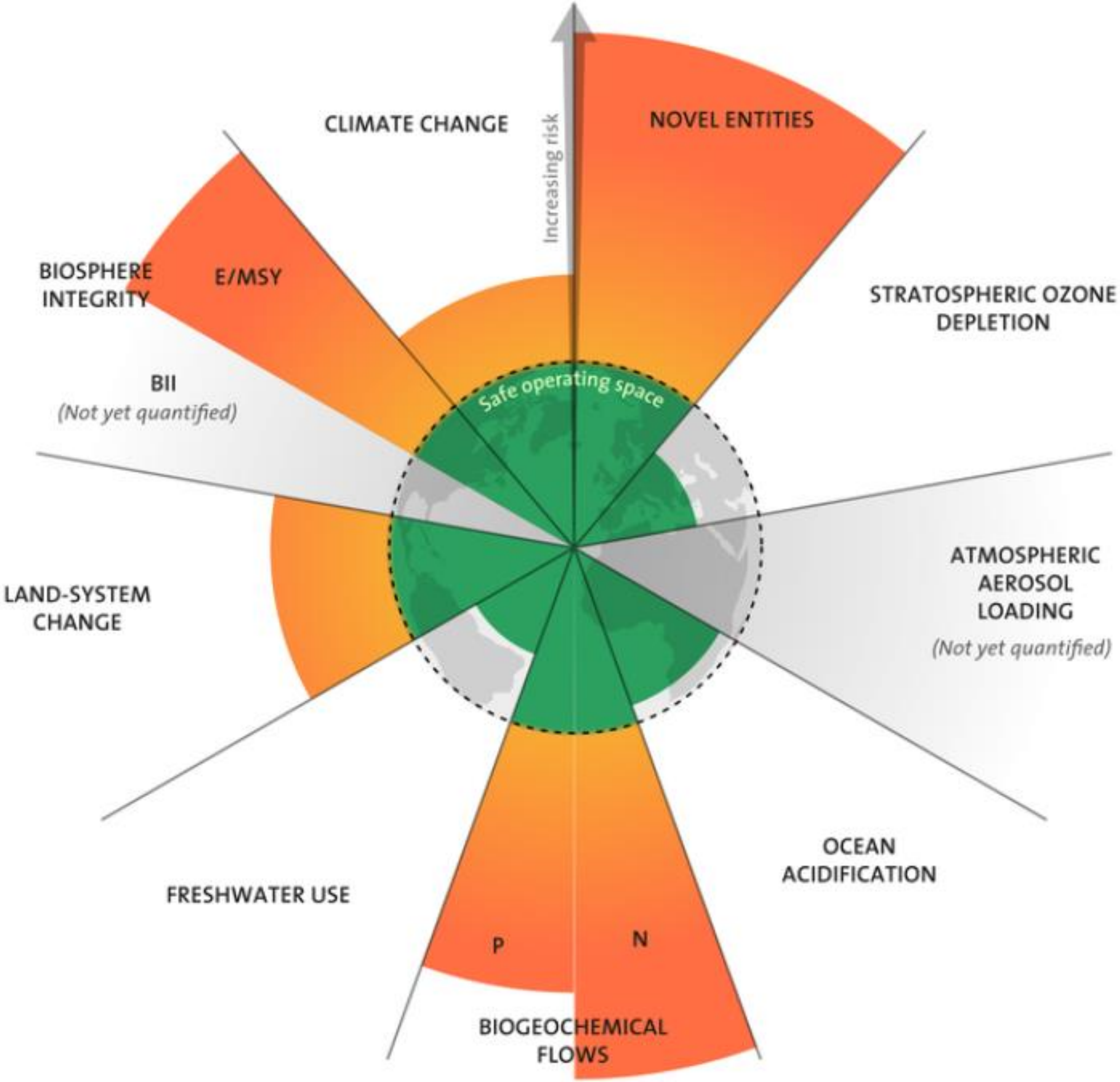
It goes without saying that, the Planetary Boundaries framework may be proved a valuable tool for evaluating the global impact of human actions and, thus, provide solid quantified scientific evidence in favour of the Anthropocene hypothesis, apart from- and beyond - a strict stratigraphic justification. Perhaps the broader perspective of PB could be evaluated as an additional scientific tool and compared with stratigraphic and other evidence, for the better understanding and, consequently, the better articulation of the formal proposal of AWG towards Anthropocene's approval. By all odds, the Anthropocene hypothesis would require an integrated interdisciplinary approach for its proper justification.

Annex I – Planetary Boundaries (2015)



Annex's Source: *J. Lokrantz/Azote based on Steffen et al. 2015.*

Annex II – Planetary Boundaries (2022)



Annex's II Source:

https://www.eurekalert.org/multimedia/814366

& Persson et al., (2022)

4. A case study: Investigating the Anthropocene hypothesis in River Deltas, Lake Basins, and Coastal ecosystems

4.1. River Deltas in the Anthropocene

River deltas play a vital role worldwide serving as runoff areas of river basins, affecting the geomorphology of coastal areas and the fluvial sediment deposition. Deltaic systems are very fragile areas, vulnerable in saltwater intrusion into coastal aquifers, highly exposed to storms, floods events, and other combined effects of both terrestrial (landward) and coastal – sea - oceanic (seaward) origin. At the same time, some of the world's major and most populous metropolitan areas are established nearby river deltaic systems (Hoitink *et al.,* 2020), while these areas are functioning as important economic hubs with global impact. According to an empirical assessment which included the sample of forty (40)[39] of the most important and largest river deltas of the world (See Fig. 44), it was estimated that they function as endpoints for river basins through draining 30% of the Earth's landmass and 42% of global terrestrial runoff (Ericson *et al.,* 2006). Nearly half a billion people inhabit within these deltaic areas. Furthermore, 20% of the deltas showcase accelerated subsidence[40] and 12% show eustatic sea level rise (See Fig. 45). Projections of the study (ibid) to 2050 reveal that about 9 million people and 28,000 km^2 of the sampled deltaic areas would face increased floods risk and increased coastal erosion. Finally, the study concludes that direct anthropogenic effects determine effective sea-level rise in most of the examined deltaic areas, while revealed a less important role for eustatic sea-level rise (ibid). In a previous section of the present study we have briefly examined the potential eustatic sea level rise (ESLR) due to the global warming (see § 3.2.4).

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[39] The examined deltas are: Amazon; Bengal; Burdekin; Chao Phraya; Colorado; Danube; Dnieper; Godavari; Grijalva; Hong; Ebro; Indus; Irrawaddy; Krishna; Lena; Mackenzie; Magdalena; Mahakam; Mahanadi; Mekong; Mississippi; Moulouya; Niger; Nile; Orinoco; Parana; Po; Rio Grande; Rhine; Rhone; Yellow; Sao Francisco; Sebou; Senegal; Shatt el Arab; Tana; Volta; Yangtze; Yukon; and Zhujiang. For more details see: Ericson *et al.,* 2006 - table 2 pp. 68-69.

[40] For subsidence see: US National Ocean Service https://oceanservice.noaa.gov/facts/subsidence.html (Retrieved 26.12.2021).

Furthermore, there are recent studies which remain critical over the potential resilience of river deltas in the era of Anthropocene, due to massive anthropogenic interaction with the natural balance of the deltaic ecosystems (Hoitink *et al.,* 2020), while others claim that at the global level human systems have transformed many deltas to an Anthropocene state (Renaud *et al.,* 2013).

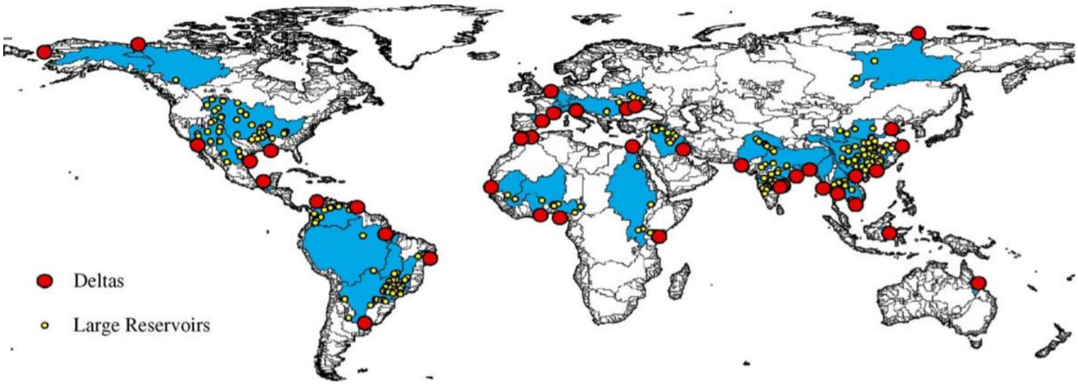

Figure 44. *Global distribution of the 40 deltas analyzed in red cycles. The potentially contributing river basin area of each delta is colored in blue and the large reservoirs (N0.5 km3 maximum capacity) in each basin are marked by yellow dots (Source: Ericson et al., 2006 – p. 64).*

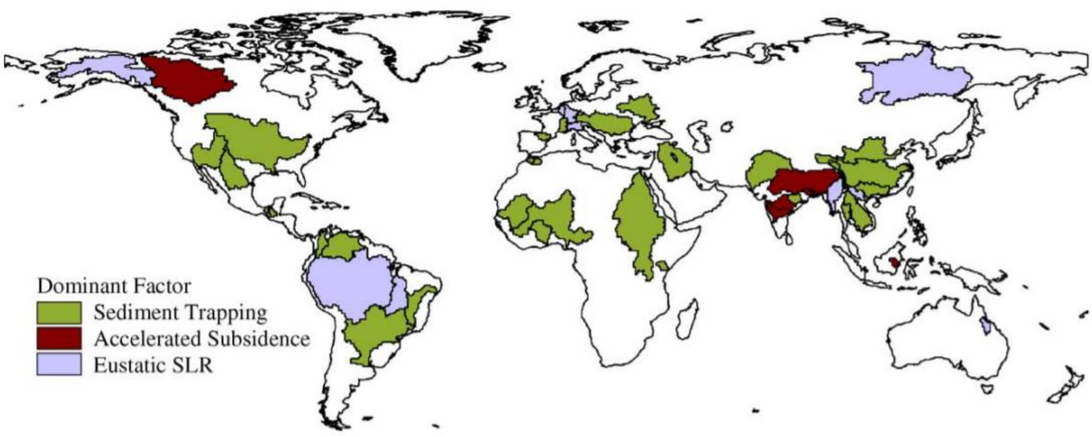

Figure 45. *Sediment trapping is the dominant factor in 27 deltas (in green color), eustatic sea level rise is the dominant factor in 8 deltas (in grey) and accelerated subsidence in 5 deltas (in red). (Source: Ericson et al., 2006 – p. 76).*

Other studies introduce theoretical projection schemes in deltaic evolution, by examining potential tipping-turning points for rivers' deltas, from Holocene's relative stability to Anthropocene's anthropogenic instability with potential collapse scenarios (Renaud *et al.,* 2013) (See also Fig. 46).

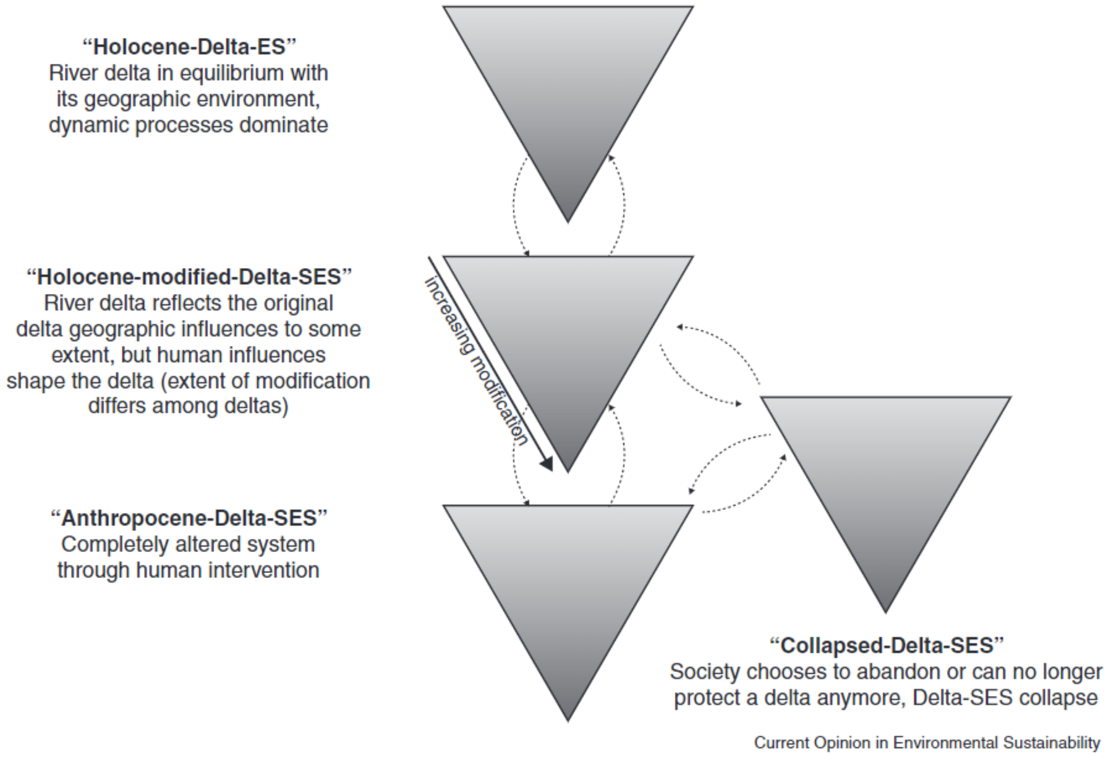

Figure 46. *Scenarios of potential Ecological System (ES) and Socio-Ecological Systems (SESs) states and tipping points for river deltas, from Holocene's "equilibrium" to Anthropocene's anthropogenic modifications with potential collapse prospects (Source: Renaud et al., 2013 - p. 646).*

According to Renaud *et al.,* (2013), 3 out of 5 major deltaic systems examined by this study are already functioning within the Anthropocene's Socio-Economic System (SES) (See Fig. 46), with increasing probability of future collapse, while only one deltaic system (Danube) is at the stage of "Holocene modified SES" and the Rhine-Meuse delta is following a backward transition from Anthropocene to modified Holocene due to implemented policy measures and mitigation actions (See Table 7).

In any case, more research is required towards this direction; nonetheless, the anthropogenic pressures on the deltaic systems provide evidence of a potential decoupling trend, from the Holocene's equilibrium to the Anthropocene's highly uncertain and altered situation, caused by human intervention.

Delta	State	Potential directions of change
Rhine-Meuse	Anthropocene to modified Holocene	Anthropocene → Modified Holocene (e.g. giving more room to nature)
Ganges	Anthropocene	Anthropocene → Collapsed (if e.g. remaining environmental features not maintained)
Indus	Anthropocene	Anthropocene → Collapsed (high demographic pressure and drastic changes in water and sediment discharge)
Mekong	Anthropocene	Anthropocene → Collapsed (if e.g. construction of dams significantly further alters water and sediment fluxes and over-reliance on engineered structures favored) Anthropocene → Modified Holocene (if limited development of dams in the lower Mekong basin and shifts in agricultural systems favored in place of reliance on engineered structures)
Danube	Holocene-modified to Anthropocene	Holocene-modified → Anthropocene (induced by human interventions and allowing for development of the region)

Table 7. *The state of five (5) major river deltas and their potential evolution according to the theoretical scenarios of Figure 46 (Source: Renaud et al., 2013 - p. 647).*

4.2. Lakes in the Anthropocene

Apart from the deltaic systems, the Holocene – Anthropocene transition is also well documented in the lake basins sedimentation. In this section, we briefly examine the sentimental evidence of the Anthropocene in the lake systems, as it is investigated by the relevant literature. Evidently, lake sediments offer a valuable natural database/record of recent environmental changes, such as climate change, changes in land uses, biodiversity loss, spread of pollutants and invasive species, as they incorporate all the physical, chemical, and biological conditions of the respective basin.

Recent studies argue that lake basins, especially the remoted ones, provide substantial stratigraphic evidence of the decoupling/transition of Holocene and/to the Anthropocene (Wolfe *et al.,* 2013). Evidently, collected sediments from more than 25 lakes in North America[41] reveal depletions in the nitrogen stable isotopic composition of sediment organic matter, thus, reflecting "*fingerprints*" of anthropogenic impacts on the global nitrogen cycle (Ibid). This stratigraphic evidence appears after 1850 yet is further accelerating between 1950-1970 and, again, after 1980 (Wolfe *et al.,* 2013; Saulnier-Talbot, 2016).

Towards the same direction, studies from Asia reach in similar results with North America, concerning the status of lake ecosystems. Specifically, many lakes in the Middle and Lower Yangtze River Basin in China, present major, and sometimes irreparable, ecological degradation during the 1950-1980 period, due to agricultural intensification, industrialization, and the ongoing human-induced climate change (Zhang *et al.,* 2018). This conclusion is further supported by evidence of high erosion, eutrophication, increased land sedimentation and increased floods in the great African lakes, where rates are increasing since 1970 (Odada *et al.,* 2020). Furthermore, pollutants from land (e.g. agricultural processes and fertilizers' use) and water-based activities (e.g. dams) are increasing threats to all the great, as well as, many other smaller lakes, since 1960, while big cities expansion and informal settlements in East Africa could be causing further eutrophication of fresh inland surface waters, as less

[41] For more details, see Wolfe *et al.,* 2013: table 1 – p. 21.

than 30% of the total sewage ends up in sewage treatment plants, while the rest is disposed directly and indirectly into streams, river and lake basins, ending up in surface and ground water aquifers.

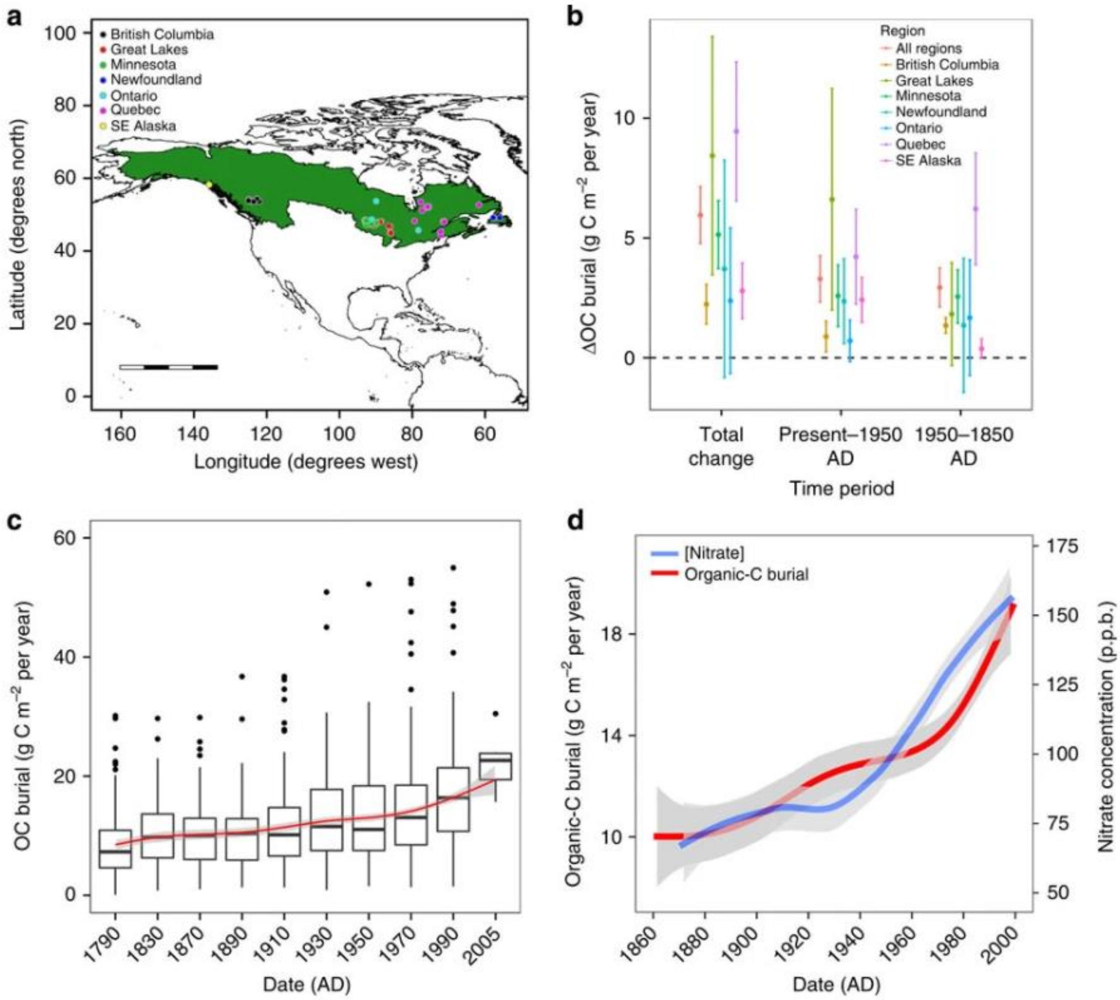

Figure 47. *(a) Map of lakes of North America, included in this study. (b) Mean change in organic-C (ΔOC) burial rates between time periods for lakes in this study for all regions (n=101), British Columbia (n=10), the Great Lakes Region (n=13), Minnesota (n=39), Newfoundland (n=4), Ontario (n=3), Québec (n=28) and southeast Alaska (n=4). (c) OC burial versus time, binned by 20-year intervals, from 1840 to 2000 AD. (d) OC burial from all lakes in this study versus time (red line) and atmospherically deposited nitrate concentrations (teal line) measured from the Greenland Ice Sheet. (Source: Heathcote et al., 2015 – p.3 -figure 1 https://www.nature.com/articles/ncomms10016.pdf)*

Other studies focusing, combined with forests carbon sink functioning, on the great lakes of North America to determine trends in organic carbon burial (Heathcote *et al.,* 2015) and, thus, trace anthropogenic impacts (Fig. 47). These organic carbon burial rates are more than five times greater than previous estimates and are increasing rapidly over the last hundred years. (Ibid – see Fig.47c-d). Paleolimnology emerges as a helpful tool for the interpretation of the lake sediments archives and tracing human-induced environmental changes (Saulnier-Talbot, 2016). Figure 48 depicts methods of defining chronology by sedimentation rate.

To sum up, the present brief review reveals that recent environmental changes are associated with anthropogenic impacts on global biogeochemical cycles and are indeed traceable on the sediment records of various lake basins worldwide. For the majority of the studies reviewed, these evidence provide sufficient proof to conclude that the Holocene epoch may ended, and hence the Anthropocene hypothesis better fits as a new era of geological transformation of current planetary dynamics, especially during the period of the *Great Acceleration* (Wolfe *et al.,* 2013; Heathcote *et al.,* 2015; Saulnier-Talbot, 2016; Odada *et al.,* 2020).

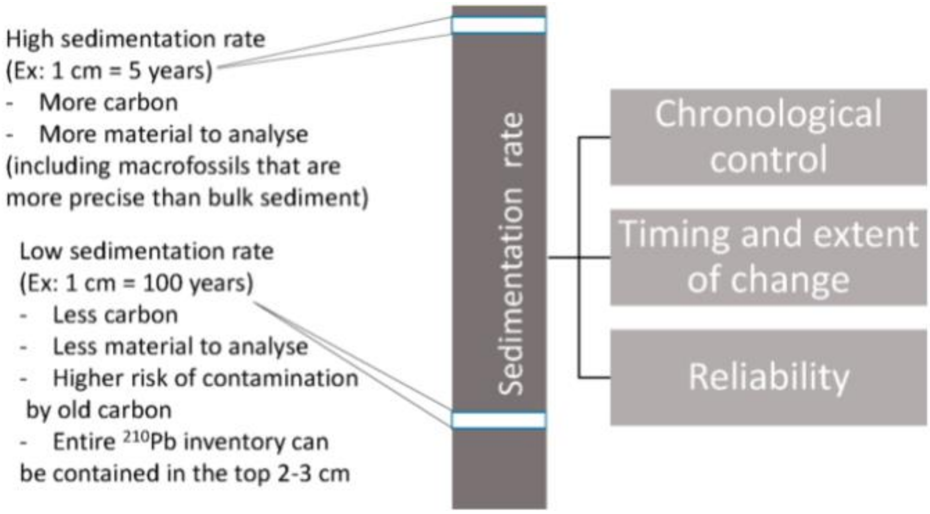

Figure 48. *Example of the way chronology is derived by sediment core in high (high sedimentation rate) and less (low sedimentation rate) productive lakes. (Source: Saulnier-Talbot, 2016 – p.2 – figure 1)*

4.3. Coastal zone in the Anthropocene

We have previously discussed the potential consequences of ocean acidification, warmth, and the estimated Sea Level Rise (SLR), caused by increased input of anthropogenic CO_2 emissions and climate change. We further extended our analysis on river deltas and lake basins, focusing on the anthropogenic impacts might be reflected in sedimental records. In this section we focus explicitly on the potential anthropogenic impacts on coastal ecosystems. Evidently, coastal zone plays a crucial role in socio-economic systems. Almost ¾ of the global population inhabits in the wider coastal zone and more than ½ of the global Gross Domestic Product (GDP), thus economic activity, is produced there (Vörösmarty *et al.,* 2009). In this sense, potential anthropogenic pressures in deteriorating coastal zones' conditions is expected to affect dramatically huge populations and critical economic activities, thus it will cause essential eco-socio-economic damage with local and global negative impacts (Wright *et al.,* 2019).

Recent studies investigate a variety of chemostratigraphic and lithostratigraphic markers of human impacts in coastal areas, as well as the evidence of the so-called "*technofossils*[42]" incorporation to the coastal sedimentary record. Metal enriched sediments, lead concentrations and stable Pb isotope ratios provide sheer evidence of human fingerprint during the *Industrial Revolution*, the period of *Great Acceleration* and nuclear bomb testing in 1960s, and are recorded in the eastern Cantabrian coast of northern Spain (Irabien *et al.,* 2015). Similarly, others investigate the presence of numerous synthetic organic substances in coastal ecosystems, where many of these pollutants is expected to stay in coastal sediments for hundreds of years or more, with potential irreversible consequences (Dachs and Méjanelle, 2010). Overall, these modifications in coastal ecosystems could be another vector of global change and, hence a potential evidence of the Anthropocene (ibid).

[42] According to PCMag Encyclopedia (sic): "*The remains of technology millions of years in the future. Geologists predict landfills full of fossilized computers, smartphones, tablets, and other electronic devices*" (Source: https://www.pcmag.com/encyclopedia/term/technofossils Retrieved 11.01.2022).

Other researchers construct models and simulations to estimate the potential consequences of human impacts on coastal ecosystems. Andersson *et al*. (2006) constructed a 600 hundred years (1700-2300) global coastal model which demonstrated that the CO_2 – carbonic acid – carbonate system of the shallow-water coastal ocean is already, and will be significantly affected under future conditions of a higher CO_2 emissions, while surface water saturation state will decrease, a clue that will also have biological impacts to calcareous organisms as it may reduce their capability to calcify. Furthermore, Ramesh *et al.* (2015) examine the *Land-Ocean Interactions in the Coastal Zone* (LOICZ) through the LOICZ project which established in 1993, as a core project of the *International Geosphere – Biosphere Programme* (IGBP)[43]. The LOICZ-IGBP project was implemented in two phases:

- 1993–2003: major investigation of coastal seas as net sources and/or sinks of atmospheric CO_2, river discharge, and biogeochemical modelling
- 2004–2014: investigation of anthropogenic impacts in coastal social-ecological systems.

In terms of biological-ecological degradation, many coastal ecosystems receive enormous flows of heavy metals, microplastics, organic nutrients and flows of nitrogen and sulphur, and various other chemical and toxic pollutants, which are utilized/or derived by industrial production, urban uses, agricultural production and aquaculture, transportation, and so on (Wright *et al.,* 2019) (See Fig. 49_C).

These local human impacts (which are being intensified in many regions and, if aggregated, obtain global perspective) could lead into degradation or even collapse of many coastal ecosystems (He and Silliman, 2019). Figures $49_{A\text{-}C}$ presents three different scenarios of coastal ecosystems' evolution, under different level of pressures coming from climate change and population density/human activities.

Finally, it is worth mentioned here that the estimated so far SLR (already presented in § 3.2.4.) and the associated risk for populous coastal zone, together with potential

[43] See more in programme's official webpage: http://www.igbp.net/ (Retrieved 12.01.2022).

increased risk of coastal floods and storms, is already leading into massive infrastructure building and "*hard engineering*" solutions to protect coastal zone from erosion and inundation (e.g. seawalls, dams, break-waters, etc.) (Bulleri and Chapman, 2010). Inevitably, this kind of interventions will further increase the direct anthropogenic impact and manmade material flows on coastal zones, thus further increase the Anthropocene's fingerprint in the decades to come.

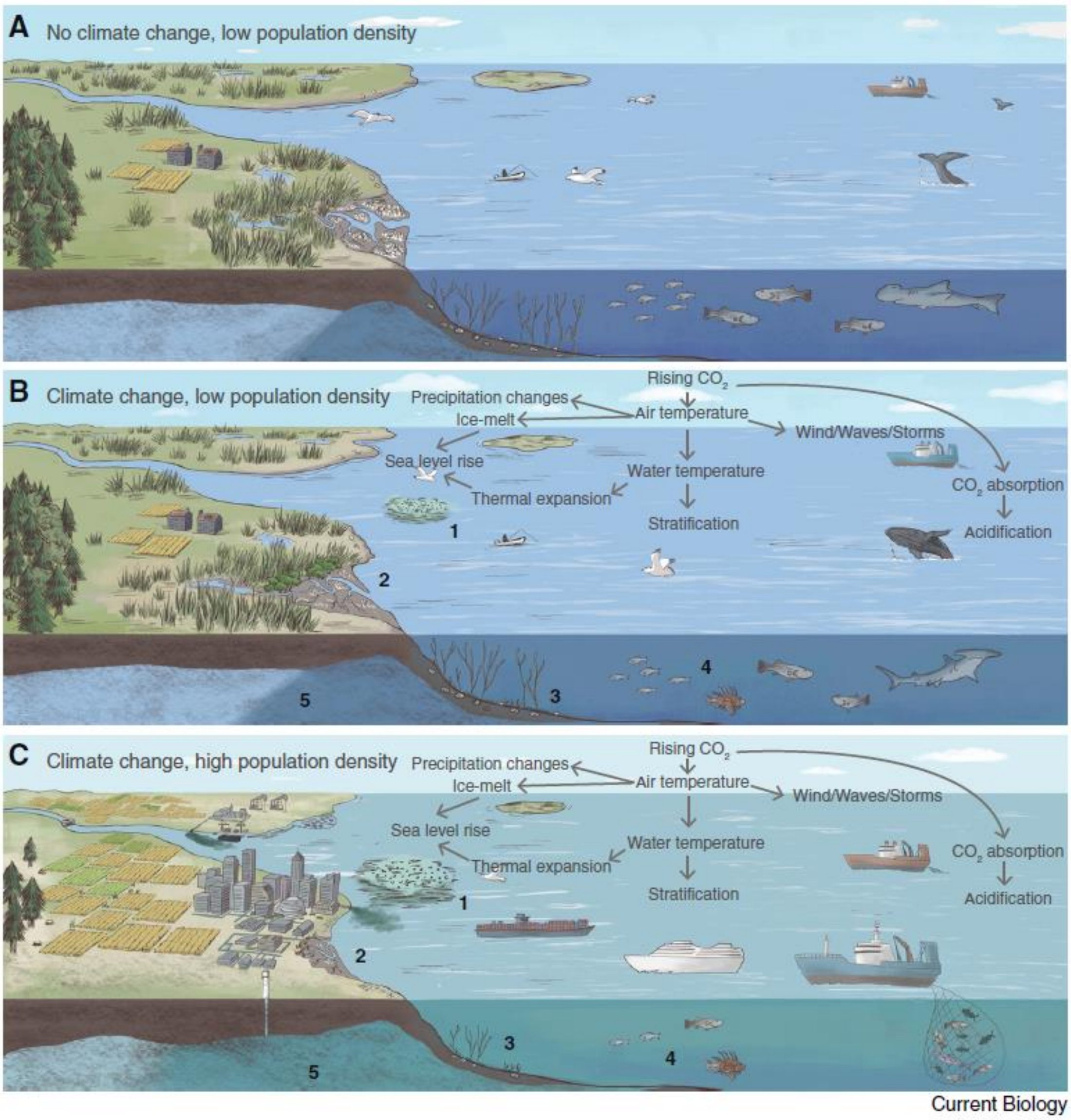

Figure 49. *Impacts of climate change and local human activities on coastal ecosystems. (A) No climate change and low population density Scenario; (B) Scenario when the system is pressured primarily by climate change, while population density remains low. (C) Scenario when the system is pressured by both climate change and intense local human impacts (Source: He and Silliman, 2019 - p.1022)*

5. Concluding remarks – *An Epilogue*

We anticipate that a formal recognition of the Anthropocene, as a new geological epoch/series, would require quite a few years – maybe by the end of the current decade (?) -, due to the tight and strict procedures of ICS and the final approval of IUGS. Moreover, it seems more likely/realistic that the Anthropocene hypothesis would engage a new stage/age within the context of the Holocene series/epoch, rather than a new epoch divergent by the Holocene. In any case, the outcome of this long-lasting debate is uncertain; perhaps there would be a formal recognition that would lead into the amendment of the current status quo in geological history, but maybe not. Criticism within the geologists against the formal recognition of Anthropocene is still persistent. Surprisingly, the latest annual report (in 2019) of the IUGS makes only one general reference to the term "Anthropocene", whilst at the same time, there is not any relevant announcement of the voting results published by the AWG's newsletter. Probably, the lack of any reference to the Anthropocene is a sheer sign of IUGS's unwillingness to take into consideration any potential amendments of the ICC, at least soon.

Be that as it may, the broad adoption of the term by numerous scientific fields and its domination in interdisciplinary research, reveals the need for a wider perception of the Anthropocene, that exceeds the realms of geology. Under this perspective, the establishment of this new era of mankind is based on a multiparametric analysis extended from the lithosphere, the hydrosphere, and the atmosphere, to the entire biosphere, through a complex multidirectional causal relationship that goes beyond the one-dimensional stratigraphic recognition of a specific GSSP "*golden spike*". Indeed, the formal recognition of an era of mankind functioning as a powerful natural/geological force goes far beyond the realms of geology and stratigraphy, as it could provide a holistic and sound pressure to the global environmental policy arena. Despite the fruitful work made so far by AWG and the derived publications, there has been an increasing criticism on the way the decisions are taken so far, in closed meetings with voting procedures; an open call for more interdisciplinary engagement, open procedures and broad peer reviewed studies for documentation, is essential

(Ellis *et al.,* 2016). Evidently, the multidimensional importance of Anthropocene's recognition, requires the engagement of various scientific fields, apart from geology-stratigraphy-geomorphology, to shape a solid, sound, and coherent framework of establishing the argumentations in favour of Anthropocene. Towards this direction, besides a broadly accepted GSSP's, a more holistic approach is more essential for the final universal approval of Anthropocene by the scientific community.

Historically, new approaches requiring major paradigm shifting are never introduced without mainstream, sometimes harsh, criticism. Evidently, the idea of a new geological epoch has raised a considerable criticism in favour of the mainstream paradigm (Πασσαλή, 2020). A representative example of an interesting ideological and academic *conflict*, begun with an article (surprisingly though, not published in an academic peer-reviewed journal) by P. Brannen (2019), where the author presents the whole Anthropocene idea as a joke, in terms of geological timescales, claiming that the entire human civilization is just a short event, not an epoch. This article triggered an interesting debate, with the AWG's reply[44] and authors' further answer[45]. Indeed, it is extremely difficult for many geologists to accept the engagement of a new epoch, whose evidence seems like a blink of the eyes once compare with the 4,5 billion years of Earth's formation. In this view, many argue that the Anthropocene concept is a part of pop culture (Autin and Holbrook, 2012), or even a political statement which must kept beyond the established, under strict stratigraphic criteria, ICS's geological time scale (Finney and Edwards, 2016).

On the other hand, the Anthropocene hypothesis is a geo-historical period, thus is consisted by two basic dimensions, one historical and one geological. In that sense, whilst many geologists remain sceptical over this new epoch, on the contrary, many professional historians are adopting, albeit in different theoretical and scientific basis,

[44] See AWG' reply here: https://www.theatlantic.com/letters/archive/2019/10/readers-defend-the-anthropocene-epoch/597571/ (Retrieved in 06.02.2022).

[45] See Brannen's reply here: https://www.theatlantic.com/science/archive/2019/10/anthropocene-epoch-after-all/599863/ (Retrieved in 06.02.2022).

the term Anthropocene (McNeill and Engelke, 2014; Harari, 2015; 2017). Furthermore, there are also interesting approaches dealing with political and ethical concerns over the decision making of coping with potential Anthropocene's adoption as a formal epoch (Dryzek and Pickering, 2018; Αποστολόπουλος, 2019; Ευθυμιόπουλος, 2017; Σκούρας, 2019; Τσιπολίτης, 2018), while others investigate the ethical - theological dimensions of the concept, in eschatological and apocalyptical terms (Grove, 2015). In line with these multidisciplinary endeavours, Lorimer (2017) reveals the intellectual complexity of the notion Anthropocene, as he identifies five ways in which the term has been mobilized and being understood by various scientific fields: as a scientific question; as an intellectual zeitgeist; as an ideological provocation; as a new ontologies; and, as a science fiction. This social-cultural-philosophical-historical-scientific intellectual zeitgeist[46] has also created a stream of numerous similar neologisms, such as *Capitalocene* (Τσιπολίτης, 2018), *Technocene* (Hornborg, 2015), and *Novacene* (Lovelock, 2019), to mention just a few representative examples.

No matter what the final outcome of the Anthropocene Working Group (AWG) might be, eventually, according to Zalasiewicz *et al.*, 2017, "*human beings are now operating as a major geological agent at the planetary scale, and that their activities have already changed the trajectory of many key Earth processes, some of them irreversibly, and in doing so have imprinted an indelible mark on the planet. This implies that the Holocene no longer serves to adequately constrain the rate and magnitude of Earth System variability*". Indeed, humanity is facing unprecedented challenges of global environmental changes, from natural resources depletion and climate change to oceans acidification, biodiversity loss and ecosystems services degradation, that will affect future generations and even question the existence of homo sapiens as a species. IPCC's sixth assessment is currently available[47] and, together with the

[46] Etymology of the term here: https://en.wikipedia.org/wiki/Zeitgeist (Retrieved in 06.02.2022).

[47] The sixth Assessment report of IPCC (2021), is available here: https://www.ipcc.ch/report/ar6/wg1/ (Retrieved 13.01.2021)

mediocre performance of global leadership in Glasgow's COP26[48] summit, underlines the inadequacy of commitment in urgency of implementing the climate targets and the moderate progress towards mitigation and adaptation to climate change, at the global level. In that sense, the formal recognition of the Anthropocene, as a new geological epoch, could play a decisive role towards acting more pressure to the policy makers at the global level.

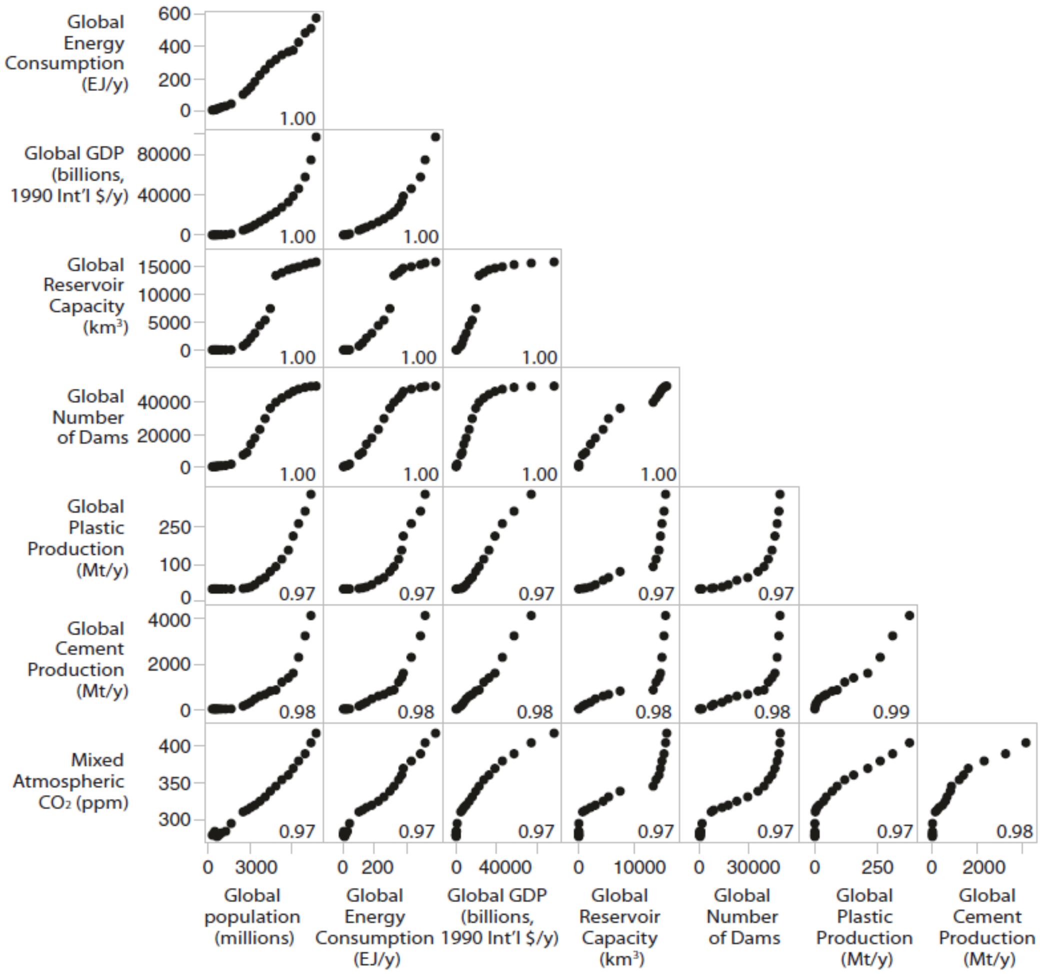

Figure 50. *Statistical relationships between human population, productivity, and energy, and key environmental indicators. Correlation-matrix displayed as cross plots estimates of global human population (millions), global human energy consumption (EJ/y), global GDP (billions, 1990 Int'l $/y), global reservoir capacity (km3; year-end), global number of large dams (year-end), global plastic production (year-end), global cement production (year-end), mixed atmospheric CO2 (mid-year). (Source: Syvitski et al., 2020).*

48 More in COP26 UN's Climate Change Conference in Glasgow, the UK (2021) here: https://ukcop26.org/ (Retrieved 13.01.2021)

The main aim of the present thesis was to trace and quantify the dramatic anthropogenic impacts on various key environmental-social-economic-demographic variables. Especially after 1950, most of the examined variables seems to accelerate their trends, revealing the reasoning why this period is called as the "*Great Acceleration*". Artificial new forms of matter are entering in human-natural systems during this period (e.g. plastics, radioisotopes), new manmade chemical and organic substances are constantly being invented, while the so-called "*Technosphere*" accounts for more than a billion artificial entities (Ευθυμιόπουλος, 2017). Remarkably, a calculation took place recently about the aggregate weight of all manmade creations (products, infrastructure, and waste), reaching the 30 trillion tones (!), thus every square meter of Earth's surface exerts a pressure of 50 kg of manmade materials (ibid), and is about to surpass the weight of all living things on planet Earth[49]. Syvitski *et al.,* (2020) provide an interesting wholistic overview of the main socio-economic trends, that may serve as a concluding figure to the present study (Fig. 50). What is more, an interesting assessment of sixteen brief points-arguments advocating the need to adopt the Anthropocene hypothesis, provides a brilliant overview (ibid):

1. The anthropogenic N cycle is almost equivalent to the global natural N cycle.
2. River systems are highly affected globally due to the contraction of dams, reservoirs, and diversions. (Only 23% of rivers, longer than 1,000 km, flow uninterrupted to the coastal ocean).
3. Global roads and highways network (about 64 million kilometres) required about 200 Gt of sand and gravel to support the traffic of 1 billion motor vehicles.
4. Global industrial mining has exceeded the power of land transported by natural processes (ice, water, wind).
5. Industrial-scale agriculture accounts for 50% of terrestrial soil loss.

[49] More on this estimation here: https://www.nationalgeographic.com/environment/article/human-made-materials-now-equal-weight-of-all-life-on-earth (Retrieved in 13.02.2022)

6. Compounds such as DDT, CFCs, and pesticides are highly persistent in the environment despite and have left a clear signal in the sedimentary record, during the last fifty years.
7. Coastal engineering has led to the disturbance of the natural coastal sedimentation, creating erosion.
8. Microplastics are detected almost worldwide, forming another candidate marker of Anthropocene's strata.
9. Human-mediated mineral species and synthetic mineral-like compounds now exceed 180,000.
10. Global cement and concrete production are 4 Gt/y and 27 Gt/y, respectively.
11. Human-Induced Climate change by anthropogenic CO_2 and other emissions.
12. Over exploitation of global fishery is expected to cause, or already causing, a collapse in natural numbers of fish species.
13. Global aggregate biomass of modern human-cultivated crops is about 10 Gt.
14. Anthropogenic emissions of sulphur-containing gases exceed natural fluxes by 2 to 3 times.
15. Since the late 20^{th} century, the number of invasive species has increased dramatically, signalling anthropogenic disturbances in ecosystems.
16. Finally, the most widespread and globally synchronous human signal is the outcome of the nuclear weapons' testing, started in 1945. Due to their very long persistence, some of these radionuclides will be detectable into the long-run future, for about 100 ky, marking another potential marker of Anthropocene's strata.

Evaluating these dynamics, someone might anticipate that a formal recognition could further trigger more action towards building strongest sustainability perspective. Apparently, the multidimensional anthropogenic impacts on the natural system demands a brave interdisciplinary justification and acceptance. Moreover, the formal engagement of an Anthropocene's era, in the global political and decision makers' arena, could boost the mutual understanding and opinion convergence concerning more immediate, decisive, and solid action towards confronting humanity's major environmental challenges.

In any case, perhaps the best epilogue to the present thesis belongs to the very own thoughts of the initial inspirators; in their own words, two decades ago, that still sound so up to date, Crutzen & Stoermer (2000-p.18), concluded that (sic):

> "*Without major catastrophes like an enormous volcanic eruption, an unexpected epidemic, a large-scale nuclear war, an asteroid impact, a new ice age, or continued plundering of Earth's resources by partially still primitive technology (the last four dangers can, however, be prevented in a real functioning noösphere) mankind will remain a major geological force for many millennia, maybe millions of years, to come. To develop a world-wide accepted strategy leading to sustainability of ecosystems against human induced stresses will be one of the great future tasks of mankind, requiring intensive research, efforts and wise application of the knowledge thus acquired in the noösphere, better known as knowledge or information society. An exciting, but also difficult and daunting task lies ahead of the global research and engineering community to guide mankind towards global, sustainable, environmental management".*

6. Literature – References – Databases

6.1. Literature in English

Andersson, A. J., Mackenzie, F. T., & Lerman, A., (2006). Coastal ocean CO2–carbonic acid–carbonate sediment system of the Anthropocene. Global Biogeochemical Cycles, 20(1).

Andrew, R.M., Peters, G.P., (2021). The Global Carbon Project's fossil CO2 emissions dataset, Zenodo. Available at: https://doi.org/10.5281/zenodo.5569234

Autin, W. J., & Holbrook, J. M., (2012). Is the Anthropocene an issue of stratigraphy or pop culture? GSA Today, 22(7), 60-61.

Bakker, P., Schmittner, A., Lenaerts, J. T. M., Abe-Ouchi, A., Bi, D., van den Broeke, M. R., et al., (2016). Fate of the Atlantic Meridional Overturning Circulation: Strong decline under continued warming and Greenland melting. Geophysical Research Letters, 43(23), 12-252.

Boers, N., (2021). Observation-based early-warning signals for a collapse of the Atlantic Meridional Overturning Circulation. Nature Climate Change, 11(8), 680-688.

Bonneuil, C., Choquet, P. L., & Franta, B., (2021). Early warnings and emerging accountability: Total's responses to global warming, 1971–2021. Global Environmental Change, 102386.

Brannen, P., (2019). The Anthropocene is a Joke. On geological timescales, human civilization is an event, not an epoch. The Atlantic, August 2019. Available at: https://www.theatlantic.com/science/archive/2019/08/arrogance-anthropocene/595795/

Broecker, W. S., & Stocker, T. F., (2006). The Holocene CO2 rise: Anthropogenic or natural?. Eos, Transactions American Geophysical Union, 87(3), 27-27.

Brunner, P. H., & Rechberger, H., (2004). Methodology of MFA. Practical Handbook of Material Flow Analysis. Washington DC: Lewis Publishers.

Buchholz, B. A., Alkass, K., Druid, H., & Spalding, K. L., (2018). Bomb pulse radiocarbon dating of skeletal tissues. In New Perspectives in Forensic Human Skeletal Identification (pp. 185-196). Academic Press.

Buffon, Georges-Louis Leclerc de (1778). Histoire naturelle générale et particulière, Supplément 5: Des e ́poques de la nature. Paris: Imprimerie royale.

Bulleri, F., and Chapman, M. G., (2010). The introduction of coastal infrastructure as a driver of change in marine environments. Journal of Applied Ecology, 47(1), 26-35.

Caesar, L., Rahmstorf, S., Robinson, A., Feulner, G., & Saba, V., (2018). Observed fingerprint of a weakening Atlantic Ocean overturning circulation. Nature, 556(7700), 191-196.

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., & Palmer, T. M., (2015). Accelerated modern human–induced species losses: Entering the sixth mass extinction. Science advances, 1(5), e1400253.

Certini, G., Scalenghe, R., (2011). Anthropogenic soils are the golden spikes for the Anthropocene. The Holocene 21, 1269–1274.

Corcoran, P. L., Jazvac, K., & Ballent, A., (2018). Plastics and the anthropocene. Encycl. Anthropocene, Vol1, pp. 163-170.

Crosby, A. W., (2016). The columbian exchange (pp. 427-434). University of California Press.

Crutzen P.J. (2006). The “Anthropocene”. In: Ehlers E., Krafft T. (eds) Earth System Science in the Anthropocene. Springer, Berlin, Heidelberg. https://doi.org/10.1007/3-540-26590-2_3

Crutzen, P. (2002). Geology of mankind. Nature 415, 23 https://doi.org/10.1038/415023a

Crutzen, P. J., & Stoermer, E. F. (2000). The Anthropocene IGBP newsletter, 41. Royal Swedish Academy of Sciences, Stockholm, Sweden.

Crutzen, P. J., & Stoermer, E. F. (2013). "The 'Anthropocene'''(2000). In The Future of Nature (pp. 479-490). Yale University Press.

Dachs, J., & Méjanelle, L., (2010). Organic pollutants in coastal waters, sediments, and biota: a relevant driver for ecosystems during the anthropocene?. Estuaries and Coasts, 33(1), 1-14.

De-la-Torre, G. E., Dioses-Salinas, D. C., Pizarro-Ortega, C. I., & Santillán, L., (2021). New plastic formations in the Anthropocene. Science of the Total Environment, 754, 142216.

DellaSala, D. A., and Goldstein, M. I. (eds.), (2018). Encyclopedia of the Anthropocene (Vols. 1-5). Elsevier.

DellaSala, D. A., Goldstein, M. I., Elias, S., Jennings, B., Lacher, T. E., Mineau, P., & Pyare, S., (2018). The Anthropocene: how the great acceleration is transforming the planet at unprecedented levels. Encyclopedia of the Anthropocene, Vol.1, pp. 1-7.

Doney, S. C., Fabry, V. J., Feely, R. A., & Kleypas, J. A., (2009). Ocean acidification: the other CO2 problem. Annual review of marine science, 1, 169-192.

Doughty, C.E., Wolf, A., Field, C.B., (2010). Biophysical feedbacks between the Pleistocene megafauna extinction and climate: the first human-induced global warming? Geophysical Research Letters 37, L15703.

Drijfhout, S., Van Oldenborgh, G. J., & Cimatoribus, A. (2012). Is a decline of AMOC causing the warming hole above the North Atlantic in observed and modeled warming patterns?. Journal of Climate, 25(24), 8373-8379.

Dryzek, J. S., & Pickering, J., (2018). The politics of the Anthropocene. Oxford University Press.

Duchez, A., Frajka-Williams, E., Josey, S. A., Evans, D. G., Grist, J. P., Marsh, R., et al., (2016). Drivers of exceptionally cold North Atlantic Ocean temperatures and their link to the 2015 European heat wave. Environmental Research Letters, 11(7), 074004.

EIA (Environmental Investigation Agency), 2022. Ocean. Connecting the dots. Plastic pollution and the planetary emergency. January 2022, Edition of EIA, London, UK: Available:https://eia-international.org/wp-content/uploads/2022-EIA-Report-Connecting-the-Dots-SPREADS.pdf

Elias, S. A. (2018). Plastics in the Ocean. Encycl. Anthropocene, 1, 133-149.

Elias, S. A., (2018). Finding a “Golden Spike” to Mark the Anthropocene. Encyclopedia of the Anthropocene, Vol.1, pp. 19-28.

Ellis, E., Maslin, M., Boivin, N., & Bauer, A., (2016). Involve social scientists in defining the Anthropocene. Nature News, 540(7632), 192.

Ericson, J. P., Vörösmarty, C. J., Dingman, S. L., Ward, L. G., & Meybeck, M., (2006). Effective sea-level rise and deltas: Causes of change and human dimension implications. Global and Planetary Change, 50(1-2), 63-82.

Finney, S.C., & Edwards, L.E., (2016). The “Anthropocene” epoch: Scientific decision or political statement. Gsa Today, 26(3), 4-10.

Fischer, E., (1915). Der Mensch als geologischer Faktor. Zeitschrift der Deutschen Geologischen Gesellschaft, 106-148.

Foley, S. F., Gronenborn, D., Andreae, M. O., Kadereit, J. W., Esper, J., Scholz, D., ... & Crutzen, P. J., (2013). The Palaeoanthropocene – The beginnings of anthropogenic environmental change. Anthropocene, 3, 83-88. https://doi.org/10.1016/j.ancene.2013.11.002

Friedlingstein et al., (2021): The Global Carbon Budget 2021, Earth System Science Data. Available at: https://essd.copernicus.org/preprints/essd-2021-386/

Fuller, D.Q., van Etten J., Manning K., Castillo C., Kingwell-Banham E., et al., (2011). The contribution of rice agriculture and livestock pastoralism to prehistoric methane levels: an archeological assessment. Holocene 21:743–59.

Gibbard, P. L., Head, M. J., Walker, M. J., & the Subcommission on Quaternary Stratigraphy, (2010). Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma. Journal of Quaternary Science, 25(2), 96-102.

Glikson, A., (2013). Fire and human evolution: The deep-time blueprints of the Anthropocene. Anthropocene, 3, 89-92.

Gowdy, J., & Krall, L., (2013). The ultrasocial origin of the Anthropocene. Ecological Economics, 95, 137-147.

Grove, J. (2015). Of an apocalyptic tone recently adopted in everything: the Anthropocene or peak humanity?. Theory & Event, 18(3).

Guinotte, J. M., & Fabry, V. J., (2008). Ocean acidification and its potential effects on marine ecosystems. Annals of the New York Academy of Sciences, 1134(1), 320-342.

Guo, W., Bokade, R., Cohen, A. L., Mollica, N. R., Leung, M., & Brainard, R. E., (2020). Ocean acidification has impacted coral growth on the great barrier reef. Geophysical Research Letters, 47(19), e2019GL086761. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019GL086761

Gutow, L., & Bergmann, M., (2017). Contamination of our oceans by plastics. Reference Module in Earth Systems and Environmental Sciences. https://epic.awi.de/id/eprint/43252/

Hallmann, N., Camoin, G., Eisenhauer, A., Botella, A., Milne, G. A., Vella, C., et al., (2018). Ice volume and climate changes from a 6000 year sea-level record in French Polynesia. Nature communications, 9(1), 1-12.

He, Q., & Silliman, B. R., (2019). Climate change, human impacts, and coastal ecosystems in the Anthropocene. Current Biology, 29(19), R1021-R1035.

Heathcote, A. J., Anderson, N. J., Prairie, Y. T., Engstrom, D. R., & Del Giorgio, P. A., (2015). Large increases in carbon burial in northern lakes during the Anthropocene. Nature Communications, 6(1), 1-6.

Hoitink, A. J., Nittrouer, J. A., Passalacqua, P., Shaw, J. B., Langendoen, E. J., Huismans, Y., & van Maren, D. S., (2020). Resilience of river deltas in the Anthropocene. Journal of Geophysical Research: Earth Surface, 125(3).

Hönisch, B., Ridgwell, A., Schmidt, D. N., Thomas, E., Gibbs, S. J., Sluijs, A., et al., (2012). The geological record of ocean acidification. science, 335(6072), 1058-1063.

Hornborg, A., (2015). The political ecology of the Technocene: Uncovering ecologically unequal exchange in the world-system. In: Hamilton, C., Bonneuil, C., & Gemenne, F. (Eds.). *The Anthropocene and the global environmental crisis*. London: Routledge, pp. 57-69.

Irabien, M. J., García-Artola, A., Cearreta, A., & Leorri, E., (2015). Chemostratigraphic and lithostratigraphic signatures of the Anthropocene in estuarine areas from the eastern Cantabrian coast (N. Spain). Quaternary International, 364, 196-205.

Jenkyn, T. W., (1854). Lessons in Geology XLVI. Chapter IV. On the effects of organic agents on the Earth's crust. Popular Educator, 4, 139-141.

Johnson, C. N., Balmford, A., Brook, B. W., Buettel, J. C., Galetti, M., Guangchun, L., & Wilmshurst, J. M., (2017). Biodiversity losses and conservation responses in the Anthropocene. Science, 356(6335), 270-275.

Johnston, H., (1971). Reduction of stratospheric ozone by nitrogen oxide catalysts from supersonic transport exhaust. Science, 173(3996), 517-522.

Kalimeris, P., (2015). Natural resources in the production process: aggregate scarcity and constraints in the context of sustainable development (Doctoral dissertation, Πάντειο Πανεπιστήμιο Κοινωνικών και Πολιτικών Επιστημών. Τμήμα Οικονομικής και Περιφερειακής Ανάπτυξης. Ινστιτούτο Αστικού Περιβάλλοντος και Ανθρώπινου Δυναμικού).

Kalimeris, P., (2018). Ecce Homo-Economicus? The Dr. Jekyll & Mr. Hide syndrome of the economic man in the context of natural resources scarcity and environmental externalities. Journal of Philosophical Economics, 12(1), 89-111.

Kalimeris, P., Bithas, K., Richardson, C., & Nijkamp, P., (2020). Hidden linkages between resources and economy: A "Beyond-GDP" approach using alternative welfare indicators. Ecological Economics, 169, 106508.

Krausmann, F., & Langthaler, E., (2019). Food regimes and their trade links: A socio-ecological perspective. Ecological Economics, 160, 87-95.

Krausmann, F., Lauk, C., Haas, W., & Wiedenhofer, D., (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. Global Environmental Change, 52, 131-140.

Langematz, U., (2019). Stratospheric ozone: down and up through the anthropocene. ChemTexts, 5(2), 1-12.

Lau, W. W., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., et al., (2020). Evaluating scenarios toward zero plastic pollution. Science, 369(6510), 1455-1461.

Lewis, S. L., & Maslin, M. A., (2015). Defining the anthropocene. Nature, 519(7542), 171-180.

Lorimer, J. (2017). The Anthropo-scene: A guide for the perplexed. Social Studies of Science, 47(1), 117-142.

Lovelock, J. (2019). Novacene: The coming age of hyperintelligence. Cambridge Massachusetts: MIT Press.

Ludwig, C., & Steffen, W. (2017). The 1950s as the Beginning of the Anthropocene. Reference Module in Earth Systems and Environmental Sciences, 45-56.

Maddison Project Database, (2020). By Bolt, Jutta and Jan Luiten van Zanden (2020), "*Maddison style estimates of the evolution of the world economy. A new 2020 update*".

Malhi, Y. (2017). The concept of the Anthropocene. Annual Review of Environment and Resources, 42, 77-104.

McEvedy, C., & Jones, R., (1978). Atlas of world population history. Penguin Books Ltd, Harmondsworth, Middlesex, England.

McNeill, J.R., (2000). Something new under the sun: An environmental history of the twentieth-century world (the global century series). New York: WW Norton & Company.

McNeill, J.R., and Engelke, P., (2014). The Great Acceleration. An Environmental History of the Anthropocene since 1945. Massachusetts, Cambridge: The Belknap Press of Harvard University Press.

Meeder, J. F., & Parkinson, R. W., (2018). SE Saline Everglades transgressive sedimentation in response to historic acceleration in sea-level rise: a viable marker for the base of the Anthropocene?. Journal of Coastal Research, 34(2), 490-497.

Meier, M. F., Dyurgerov, M. B., Rick, U. K., O'neel, S., Pfeffer, W. T., Anderson, R. S., et al., (2007). Glaciers dominate eustatic sea-level rise in the 21st century. Science, 317(5841), 1064-1067.

Molina, M. J., & Rowland, F. S. (1974). Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone. Nature, 249(5460), 810-812.

Neto, A. G., Langan, J. A., & Palter, J. B., (2021). Changes in the Gulf Stream preceded rapid warming of the Northwest Atlantic Shelf. Communications Earth & Environment, 2(1), 1-10.

Nicholls, R. J., Hoozemans, F. M., & Marchand, M., (1999). Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. Global Environmental Change, 9, S69-S87.

Nordgren, A., (2012). Ethical issues in mitigation of climate change: The option of reduced meat production and consumption. Journal of Agricultural and Environmental Ethics, 25(4), 563-584.

Odada, E. O., Olago, D. O., & Olaka, L. A. (2020). An East African perspective of the anthropocene. Scientific African, e00553.

Persson, L., Almroth, B.M. C., Collins, C.D., Cornell, S., de Wit, C.A., Diamond, M.L., et al., (2022). Outside the Safe Operating Space of the Planetary Boundary for Novel Entities. Environmental Science & Technology (In press) DOI: 10.1021/acs.est.1c04158

Pievani, T., (2018). Earth's sixth mass extinction event. Encyclopedia of the Anthropocene, Vol.1, pp. 259-264.

Plank, B., Streeck, J., Virág, D., Krausmann, F., Haberl, H., & Wiedenhofer, D., (2022). From resource extraction to manufacturing and construction: flows of stock-building materials in 177 countries from 1900 to 2016. Resources, Conservation and Recycling, 179, 106122.

Polaina, E., & González-Suárez, M. (2018). Extinction Risk in the Anthropocene. Encycl. Anthropocene, Vol.3, pp. 379-384.

Prentice, I. C., Farquhar, G. D., Fasham, M. J. R., Goulden, M. L., Heimann, M., Jaramillo, V. J., et al., A. (2001). The carbon cycle and atmospheric carbon dioxide. IPCC: https://hal.archives-ouvertes.fr/hal-03333974/

Ramesh, R., Chen, Z., Cummins, V., Day, J., D'Elia, C., Dennison, B., *et al.,* (2015). Land–ocean interactions in the coastal zone: Past, present & future. Anthropocene, 12, 85-98.

Renaud, F. G., Syvitski, J. P., Sebesvari, Z., Werners, S. E., Kremer, H., Kuenzer, C., et al., (2013). Tipping from the Holocene to the Anthropocene: How threatened are major world deltas?. Current Opinion in Environmental Sustainability, 5(6), 644-654.

Roebroeks, W., & Villa, P., (2011). On the earliest evidence for habitual use of fire in Europe. Proceedings of the National Academy of Sciences, 108(13), 5209-5214.

Rovere, A., Stocchi, P., & Vacchi, M., (2016). Eustatic and relative sea level changes. Current Climate Change Reports, 2(4), 221-231.

Ruddiman W. F., (2003). The atmospheric greenhouse era began thousands of years ago. Clim. Change 61: 261–93

Ruddiman W. F., (2007). The early anthropogenic hypothesis: challenges and responses. Rev. Geophys. 45: RG4001.

Ruddiman, W. F., (2013). The anthropocene. Annual Review of Earth and Planetary Sciences, 41, 45-68.

Ruddiman, W.F., Thomson, J.S., (2001). The case for human causes of increased atmospheric CH4 over the last 5000 years. Quaternary Science Reviews 20, 1769–1777.

Rudwick, M. J. R., (2005). Bursting the limits of time. The Reconstruction of Geohistory in the Age of Revolution. Chicago: University of Chicago Press. https://doi.org/10.7208/9780226731148

Saulnier-Talbot, É. (2016). Paleolimnology as a tool to achieve environmental sustainability in the Anthropocene: An overview. Geosciences, 6(2), 26.

Smil, V., (2014). Making the modern world: materials and dematerialization. The UK: John Wiley and Sons, Ltd.

Steffen W, Broadgate W, Deutsch L, Gaffney O, Ludwig C. (2015). The trajectory of the Anthropocene: The Great Acceleration. The Anthropocene Review 2(1):81-98. https://doi.org/10.1177/2053019614564785

Steffen Will, Grinevald Jacques, Crutzen Paul and McNeill John (2011). The Anthropocene: conceptual and historical perspectivesPhil. Trans. R. Soc. A.369842–867. http://doi.org/10.1098/rsta.2010.0327

Steffen, W., (2013). Commentary: Paul J. Crutzen and Eugene F. Stoermer, "The Anthropocene" (2000). The Future of Nature, 486-490.

Stocker, B. D., Strassmann, K., & Joos, F., (2011). Sensitivity of Holocene atmospheric CO 2 and the modern carbon budget to early human land use: analyses with a process-based model. Biogeosciences, 8(1), 69-88.

Stocker, T., et al., (Eds.). (2014). Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge university press.

Subramanian, M., (2019). Anthropocene now: Influential panel votes to recognize Earth's new epoch. Nature, NEWS 21.05.2019. https://doi.org/10.1038/d41586-019-01641-5

Syvitski, J., Waters, C. N., Day, J., Milliman, J. D., Summerhayes, C., Steffen, W., et al., (2020). Extraordinary human energy consumption and resultant geological impacts beginning around 1950 CE initiated the proposed Anthropocene Epoch. Communications Earth & Environment, 1(1), 1-13.

Tarolli, P., Sofia, G., & Cao, W., (2018). The geomorphology of the human age. Encyclopedia of the Anthropocene, Vol.1, pp. 35-42.

The Conference Board Total Economy Database (2021) "Output, Labor and Labor Productivity, 1950-2021" Version: August 2021.

The Economist, (2011). The Anthropocene - A man-made world Science is recognizing humans as a geological force to be reckoned with. Briefing, May 28th of 2011 edition. Available at: https://www.economist.com/briefing/2011/05/26/a-man-made-world?story_id=18741749

The Economist, (2021). Seer of the Anthropocene. Paul Crutzen died on January (28th Feb 13th 2021) Available at: https://www.economist.com/obituary/2021/02/13/paul-crutzen-died-on-january-28th (Retrieved at 27.04.2021)

Turpin, E. and Federighi, V., (2012). A new element, a new force, a new input: Antonio Stoppani's Anthropozoic. Faculty of Engineering and Information Sciences - Papers: Part A. 2986. https://ro.uow.edu.au/eispapers/2986

Vörösmarty, C. J., Syvitski, J., Day, J., De Sherbinin, A., Giosan, L., & Paola, C., (2009). Battling to save the world's river deltas. Bulletin of the Atomic Scientists, 65(2), 31-43.

Wagler, R., (2018). 6th Mass Extinction. Encyclopedia of the Anthropocene, Vol.3, pp. 9-12.

Walker, J.S., Kopp, R.E., Little, C.M. et al., (2022). Timing of emergence of modern rates of sea-level rise by 1863. Nature Communication 13, 966. https://doi.org/10.1038/s41467-022-28564-6

Walker, M., Johnsen, S., Rasmussen, S. O., Popp, T., Steffensen, J. P., Gibbard, P., *et al.,* (2009). Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records. Journal of Quaternary Science: Published for the Quaternary Research Association, 24(1), 3-17.

Waters, C. N., Zalasiewicz, J. A., Williams, M., Ellis, M. A., & Snelling, A. M., (2014). A stratigraphical basis for the Anthropocene? Geological Society, London, Special Publications, 395(1), 1-21.

Wiedenhofer, D., Fishman, T., Plank, B., Miatto, A., Lauk, C., Haas, W., Harbel, H., & Krausmann, F., (2021). Prospects for a saturation of humanity's resource use? An analysis of material stocks and flows in nine world regions from 1900 to 2035. Global Environmental Change, 71, 102410.

Wigley, T. M. L., (1983). The pre-industrial carbon dioxide level. Climatic change, 5(4), 315-320.

Wolfe, A. P., Hobbs, W. O., Birks, H. H., Briner, J. P., Holmgren, S. U., Ingólfsson, Ó., *et al.,* (2013). Stratigraphic expressions of the Holocene–Anthropocene transition revealed in sediments from remote lakes. Earth-Science Reviews, 116, 17-34.

World Meteorological Organization (WMO) (2018) Executive summary: scientific assessment of ozone depletion: 2018, World Meteorological Organization, global ozone research and monitoring project—report no. 58, Geneva, Switzerland, p 26. (Available at: https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf - Retrieved 17.12.2021).

Wright, L. D., Syvitski, J. P. M., & Nichols, C. R., (2019). Coastal systems in the Anthropocene. In Tomorrow's Coasts: Complex and Impermanent (pp. 85-99). Springer, Cham.

WU Vienna (2020): Material flows by material group, 1970-2017. Visualisation based upon the UN IRP Global Material Flows Database. Vienna University of Economics and Business. Online available at: www.materialflows.net/visualisation-centre

Zalasiewicz, J., & Waters, C. N., (2018). Arguments for a formal global boundary stratotype section and point for the anthropocene. Encyclopedia of the anthropocene Vol.1, pp. 29-34.

Zalasiewicz, J., et al. (2017). The Working Group on the Anthropocene: Summary of evidence and interim recommendations. Anthropocene 19: 55-60. http://dx.doi.org/10.1016/j.ancene.2017.09.001

Zalasiewicz, J., Waters, C. N., Do Sul, J. A. I., Corcoran, P. L., Barnosky, A. D., Cearreta, A., et al., (2016). The geological cycle of plastics and their use as a stratigraphic indicator of the Anthropocene. Anthropocene, 13, 4-17.

Zalasiewicz, J., Williams, M., Fortey, R., Smith, A., Barry, T. L., Coe, A. L., ... & Stone, P., (2011). Stratigraphy of the Anthropocene. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 369(1938), 1036-1055.

Zalasiewicz, J., Williams, M., Smith, A., Barry, T., Coe, A., Brown, P., Brenchley, P., Cantrill, D., Gale, A., Gibbard, P., Gregory, F., Hounslow, M., Kerr, A., Person, P., Knox, R., Powell, J., Waters, C., Marshall, J., Oates, M., Peter Rawson, P., Stone, P., (2008). Are we now living in the Anthropocene? GSA Today 18, 4–8.

Zettler, E. R., Mincer, T. J., & Amaral-Zettler, L. A., (2013). Life in the “plastisphere”: microbial communities on plastic marine debris. Environmental science & technology, 47(13), 7137-7146.

Zhang, K., Yang, X., Xu, M., Lin, Q., Kattel, G., & Shen, J., (2018). Confronting challenges of managing degraded lake ecosystems in the Anthropocene, exemplified from the Yangtze River Basin in China. Anthropocene, 24, 30-39.

Zohary D., and Hopf M., (1993). Domestication of Plants in the Old World. UK: Oxford University Press.

6.2. Literature in Greek

Αποστολόπουλος, Ε., (2019). Ανθρωπόκαινο: η σημασία και η έννοια του όρου σε επιστημονικό και κοινωνικό επίπεδο. Περιοδικό Παιδαγωγικής και Εκπαίδευσης. Αθήνα: Εκδοτικός Οίκος VIPAPHARM ISSN : 2241-4665. Διαθέσιμο: http://scientific-journal-articles.org/greek/free-online-journals/education/education-articles/apostolopoulos-eustathios/anthropokaino-simasia-ennoia-orou-se-epistimoniko-koinoniko-epipedo-apostolopoulos-eustathios.htm (Ανακτήθηκε στις 02.02.2022).

Ευθυμιόπουλος, Η., (2017). *Το δίλλημα της Πεταλούδας. Οικολογική Ερμηνευτική και Περιβαλλοντικός Σχετικισμός*. Αθήνα: Ακαδημία Αθηνών, Κέντρον Ερεύνης Φυσικής της Ατμόσφαιρας και Κλιματολογίας, Δημοσίευμα αρ. 19. – Μαριολοπούλειο-Καναγκίνειο Ίδρυμα Επιστημών Περιβάλλοντος.

Πασσαλή, Δ. Δ. (2020). Σχολιασμένη μετάφραση από τα αγγλικά στα ελληνικά αποσπάσματος του άρθρου The Anthropocene is a Joke του Peter Brannen (No. GRI-2020-28695). Διπλωματική Εργασία Διατμηματικού Προγράμματος Μεταπτυχιακών Σπουδών Διερμηνείας και Μετάφρασης, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης. Διαθέσιμο: http://ikee.lib.auth.gr/record/321726?ln=el (Ανακτήθηκε στις 02.02.2022).

Σκούρας, Ζ., (2019). Ταξιδεύοντας στην Εποχή του Ανθρώπου. Η ζωή στην Ανθρωπόκαινο. Θεσσαλονίκη: Εκδόσεις Γερμανός.

Τσιπολίτης, Γ., (2018). Ανθρωπόκαινος ή Καπιταλόκαινος; Γέφυρες, συγκρούσεις και η ανάγκη για δράση. Διπλωματική Εργασία του Μεταπτυχιακού Προγράμματος Κοινωνιολογίας, του Τμήματος Κοινωνιολογίας του Παντείου Πανεπιστημίου: http://pandemos.panteion.gr/index.php?op=record&pid=iid:19013&lang=el (Ανακτήθηκε στις 02.02.2022).

Harari, Y.N., (2015). Sapiens. *Μια σύντομη Ιστορία του Ανθρώπου*. Αθήνα: Εκδόσεις Αλεξάνδρεια.

Harari, Y.N., (2017). Homo Deus. *Μια σύντομη Ιστορία του Μέλλοντος*. Αθήνα: Εκδόσεις Αλεξάνδρεια.

6.3. Utilized Databases and Tools

- **BP's Statistical Review of World Energy** (2021): https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html
- **Global carbon Atlas**: http://www.globalcarbonatlas.org/en/CO2-emissions
- **Global Geo-biodiversity Database**: http://geobiodiversity.com/home
- **Global Material Flows Database**: https://www.resourcepanel.org/global-material-flows-database
- **Interactive tool of stratigraphic time scale**: https://stratigraphy.org/timescale/
- **Maddison Project Database**, version 2020: https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2020?lang=en
- **Material Flows Net**: http://www.materialflows.net/visualisation-centre/
- **The Conference Board Total Economy Database™**, (2021) "Output, Labor and Labor Productivity, 1950-2021" Version: August 2021, Available at: https://www.conference-board.org/data/economydatabase
- **The Global Carbon Budget** 2021, Earth System Science Data. Available at: https://essd.copernicus.org/preprints/essd-2021-386/
- **The Global Carbon Project's** fossil CO2 emissions dataset. Available at: https://figshare.com/articles/preprint/The_Global_Carbon_Project_s_fossil_CO2_emissions_dataset/16729084/1
- **The Global Sea Level Database** (Walker *et al.,* 2022): https://www.nature.com/articles/s41467-022-28564-6#Sec10
- **WWF - Living Planet Index**: https://livingplanet.panda.org/about-the-living-planet-report

Back cover picture: *Terraced rice fields in China.* (Source: *ALEXGCS/GETTY - derived by Ellis et al., 2016 – p. 192.*)