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ΔΗΛΩΣΗ ΣΥΓΓΡΑΦΕΑ ΜΕΤΑΠΤΥΧΙΑΚΗΣ ΕΡΓΑΣΙΑΣ

Ο κάτωθι υπογεγραμμένος Καμπόλης Γεώργιος του Δημητρίου, με αριθμό μητρώου 20200029 φοιτητής του Προγράμματος Μεταπτυχιακών Σπουδών MSc in Oil and Gas Process Systems Engineering του Τμήματος Μηχανολόγων Μηχανικών της Σχολής Μηχανικών του Πανεπιστημίου Δυτικής Αττικής, δηλώνω ότι:

«Είμαι συγγραφέας αυτής της μεταπτυχιακής εργασίας και ότι κάθε βοήθεια την οποία είχα για την προετοιμασία της, είναι πλήρως αναγνωρισμένη και αναφέρεται στην εργασία. Επίσης, οι όποιες πηγές από τις οποίες έκανα χρήση δεδομένων, ιδεών ή λέξεων, είτε ακριβώς είτε παραφρασμένες, αναφέρονται στο σύνολό τους, με πλήρη αναφορά στους συγγραφείς, τον εκδοτικό οίκο ή το περιοδικό, συμπεριλαμβανομένων και των πηγών που ενδεχομένως χρησιμοποιήθηκαν από το διαδίκτυο. Επίσης, βεβαιώνω ότι αυτή η εργασία έχει συγγραφεί από μένα αποκλειστικά και αποτελεί προϊόν πνευματικής ιδιοκτησίας τόσο δικής μου, όσο και του Ιδρύματος.

Παράβαση της ανωτέρω ακαδημαϊκής μου ευθύνης αποτελεί ουσιώδη λόγο για την ανάκληση του πτυχίου μου».

Επιθυμώ την απαγόρευση πρόσβασης στο πλήρες κείμενο της εργασίας μου μέχρι 26/07/2023 και έπειτα από αίτηση μου στη Βιβλιοθήκη και έγκριση του επιβλέποντα καθηγητή.

Ο Δηλών

ABSTRACT

The rising levels of greenhouse gases such as carbon dioxide can be attributed to the rapid advancement of technology as well as the growth of the refining industry. This has necessitated a procedure referred to as "carbon footprint calculation" that calculates the amount of CO2 equivalents (CO2-eq) emissions.

After determining both direct and indirect contributors, it is possible to estimate greenhouse gas emissions and carbon footprint using the appropriate computational frameworks. In addition to the footprint calculator, more drastic measures have been proposed, such as renewed global agreements regarding the Kyoto Protocol, which has been in effect since the early 1990s, and the global "net zero" commitment, which was initially established by 2030 but later extended to 2050, with the ultimate goal of reducing emissions and limiting the observed temperature rise to 1.5 °C. In order to compute carbon footprint in a more organized and transparent manner, it is necessary to classify emissions as direct ("Scope 1"), indirect ("Scope 2"), and indirect ("Scope 3") emissions. The "Carbon Accounting Categories" subdivide each tier further into five subcategories, which include "personal," "vehicular," "purchased," and "fuel and energy" emissions.

The connection between carbon footprint and ecological footprint, which refers to the total quantity of land required to sustain an activity or people, is essential to this thesis. Carbon footprint is significant for nations, industries, corporations, and individuals because the management of the planet's natural resources is becoming an urgent issue.

Alarmed by the statistics, crucial drivers for reducing carbon emissions and achieving carbon neutrality by 2050 have been developed. Examples of such drivers include the "labeling and branding" of products, a corresponding rise in "energy efficiency standards," the reduction of "trading barriers" to encourage buyers to choose products compatible with more environmentally

friendly technologies, and the strategic application of the immediately effective "carbon pricing" tool.

The European Union's "European Climate Law," which makes climate neutrality mandatory by law, supplements the aforementioned initiatives. This legislation is supported by a well-thought-out "Low-carbon strategy for 2050," which is implemented via a road map delineating concrete goals and approaches for the main industrial emitters in Europe.

Since industrial emissions are among the most challenging to control, a set of methods that can be implemented individually or collectively is provided to liberate polluting businesses. In addition to this practical advice, a "decomposition algorithm" as well as a "mathematical optimization" have been investigated in greater depth as carbon-neutral emission strategies. The most recent technological advancements, such as AI and IoT, can also be used to successfully reduce emissions, provided they are implemented appropriately; this is particularly important for the control of systems that operate in a quality and safe manner in an industrial setting.

The petroleum processing industry is the third largest source of global greenhouse gas emissions, contributing to approximately 5% of the total. As such, it is not surprising that it is an integral component of the energy grid and global warming.

Over 98% of emissions coming from oil refineries consist of carbon dioxide. The technique of "Carbon Capture Storage" (CCS), which has an exceptionally high CO2 collection rate, has garnered the most attention for CO2 offsetting. An "energy efficiency roadmap" that monitors the use of low-carbon technologies by oil refining corporations is an additional suggestion. The latter is subdivided into "data collection - indications," in which external factors of the P.E.S.T. environment play a major part, "pathway building," which represents the specific selection and installation of options within the timeframe chosen to achieve carbon reduction, and "conclusion drawing," in which the selected technologies within the decarbonization pathway are utilized to mitigate the challenges generated by the former.

While progression toward carbon neutrality in the refining industry is unquestionably sluggish, six separate categories have been identified as potential means of achieving this objective. Relevant alternatives include Carbon Capture Usage and Storage technology, low-carbon hydrogen, increased use of renewable energy sources, enhanced energy efficiency, and residual heat recovery.

A common method for calculating the net energy consumption of a refinery unit is the "complexity weighted tonne" (CWT). The proportion of standard CO2 emissions is a vital metric when comparing multiple refineries or multiple divisions within a single refinery. Decarbonization requires a number of strategic decisions regarding the waste heat recovering system, the supplies used, the irrigation system, and the rest of the software and hardware involved, so that every stage of production is based on technological optimization.

Due to the close relationship between hydrogen consumption and refinery production techniques, three decarbonization strategies for the hydrogen-use phase have been developed. For improved outcomes, a "carbon capture, utilization, and storage" (CCUS) technology-based "decarbonization philosophy" is required, in which CO2 is captured from large point sources, compressed, transported, and used in a variety of applications or injected into deep geological formations.

The authors also refer to other approaches that have been previously developed and adopted by business executives, such as the "Net Carbon Footprint" model developed by Shell, which has made major pledges toward global targets by 2050. The term "life cycle" is used here to refer to not only the numerous phases of a product's creation, from the procurement of raw materials to its ultimate delivery to the final final consumer, but also the recycling and repurposing of various byproducts and product streams.

Not only have major companies assumed weighty responsibilities, but so have a number of lesser ones. Hellenic Energy, a Greek energy provider, has been in operation for over four decades and has developed in line with the European Union's (EU) "Vision 5050. Hellenic Energy is also a member of

FuelsEurope, an organization that advocates the idea that refineries can be transformed into the power hubs for energy and environmentally responsible products required to attain a carbon-neutral economy and society. The refinery in the Aspropyrgos region is a prominent example of the Group's efforts over the past four years to enhance its refining facilities and production divisions. In terms of upgrading the refinery and adopting a novel approach for improving sustainability and reducing greenhouse gas emissions, significant changes have been made since 2019.

KEYWORDS

- Carbon footprint
- Ecological footprint
- Carbon footprint calculation
- Greenhouse gas emissions (GHG)
- Emissions calculation
- CO_2 & CO_2 eq
- H_2O / CH_4 / N_2O/ O_3/
- Fossil Fuels
- Fuel gas
- Hydrogen industry
- Kyoto Protocol
- Net zero commitment
- Decarbonization Strategies
- Carbon Neutrality
- Low carbon strategy
- Direct / Indirect emissions

- Scope 1 /Scope 2/ Scope 3 emissions
- Global warming
- Energy efficiency Roadmap
- Best Available Technologies
- European Climate Law
- Carbon Capture Storage (CCS)
- Carbon Capture & Utilization Storage (CCUS)
- Renewable energy sources (RES)
- Decomposition algorithm
- IoT, AI
- Oil refinery
- Oil & Gas Industry
- Stationary combustion sources
- Catalytic cracking unit
- Storage Tanks
- Reduction Methods
- CWT approach
- Combustion Technology
- NCF model
- Oil supply chain
- Hellenic Energy

ΠΕΡΙΛΗΨΗ

Η ταχεία τεχνολογική πρόοδος και η ανάπτυξη της βιομηχανίας των διυλιστηρίων σχετίζονται άμεσα με τις αυξημένες εκπομπές αερίων θερμοκηπίου, συμπεριλαμβανομένου του CO_2. Το γεγονός αυτό οδήγησε στην ανάγκη μέτρησης της ποσότητας των εκπομπών που εκφράζονται σε ισοδύναμα διοξειδίου άνθρακα, προς διευκόλυνση, μια διαδικασία, γνωστή ως υπολογισμός «αποτυπώματος άνθρακα».

Όλοι οι υπολογισμοί για την εκτίμηση του αποτυπώματος άνθρακα και των εκπομπών αερίων του θερμοκηπίου πραγματοποιούνται κατόπιν προσδιορισμού των «άμεσων» και «έμμεσων» πηγών του. Εκτός από τα εργαλεία μέτρησης, έχουν τεθεί σε εφαρμογή ακόμη πιο δραστικές ενέργειες, όπως οι ανανεούμενες δεσμεύσεις των χωρών και οικονομιών παγκοσμίως, αλλά και η παγκόσμια δέσμευση του «καθαρού μηδέν», που είχε αρχικά καθοριστεί να εφαρμοστεί μέχρι το 2030, ωστόσο επεκτάθηκε έως το 2050, με απώτερο στόχο τη μείωση των εκπομπών και τον περιορισμό της αύξησης της θερμοκρασίας που έχει σημειωθεί κατά 1,5 °C. Η κατανομή των εκπομπών σε άμεσες, συνιστώσες του «Πεδίου Εφαρμογής 1» και σε έμμεσες, που σχηματίζουν τις εκπομπές του «Πεδίου Εφαρμογής 2» και του «Πεδίου Εφαρμογής 3», είναι απαραίτητη για τον υπολογισμό του αποτυπώματος άνθρακα με πιο δομημένο και σαφή τρόπο για πιο ακριβή αποτελέσματα. Όμως η ανάλυση τριών επιπέδων στα «Πεδία Εφαρμογής» δεν είναι η μόνη διάκριση μεταξύ των εκπομπών, καθώς υπάρχουν περισσότερες ταξινομήσεις όπως οι «Λογιστικές Κατηγορίες Άνθρακα», που αναλύουν κάθε επίπεδο σε περισσότερες κατηγορίες εκπομπών συνολικού αθροίσματος 15 στον αριθμό. Ορισμένες από αυτές αναφέρονται σε «ατομικές εκπομπές», «εκπομπές οχημάτων», «εκπομπές από τις αγορές αγαθών και υπηρεσιών» και εκείνες που σχετίζονται με «καύσιμα και ενέργεια».

Ένα σημαντικό σημείο αυτής της εργασίας είναι επίσης η συσχέτιση του αποτυπώματος άνθρακα με το συνολικό οικολογικό αποτύπωμα, το οποίο μετράται στη συνολική έκταση γης που απαιτείται για να διατηρηθεί μια δραστηριότητα ή ένας πληθυσμός. Η διαχείριση των οικολογικών περιουσιακών στοιχείων του πλανήτη γίνεται κεντρικό ζήτημα για τους

υπεύθυνους λήψης αποφάσεων σε όλο τον κόσμο, έτσι ώστε το αποτύπωμα άνθρακα να αποτελεί φλέγον ζήτημα μεταξύ χωρών, βιομηχανιών, επιχειρήσεων και ατόμων.

Ως συνέπεια των ανησυχητικών αποτελεσμάτων που προκύπτουν από τους υπολογισμούς, έχουν καθοριστεί βασικοί παράγοντες για τον περιορισμό του αποτυπώματος άνθρακα και την υποβοήθηση στην εκπλήρωση των στόχων ουδετερότητας έως το 2050. Αυτοί οι παράγοντες περιλαμβάνουν την «συσκευασία και σήμανση» των προϊόντων που πωλούνται, την επιτακτική αύξηση των « προτύπων ενεργειακής απόδοσης», τρόπους για τη μείωση των «συναλλακτικών εμποδίων» όπως και για την ενίσχυση των παικτών της αγοράς που ευθυγραμμίζονται με τεχνολογίες καθαρότερης ενέργειας και, τέλος, η στρατηγική χρήση του εργαλείου «τιμολόγηση του άνθρακα», που έχει τα αμεσότερα αποτέλεσμα.

Οι παραπάνω προσπάθειες συμπληρώνονται με την επιβολή του «Ευρωπαϊκού Νόμου για το Κλίμα», ένας νόμος με στόχο της κλιματικής «ουδετεροποίηση». Πίσω από το νόμο υπάρχει μια καλά σχεδιασμένη «στρατηγική χαμηλών εκπομπών άνθρακα για το 2050», η οποία εφαρμόζεται μέσα από έναν «Οδικό Χάρτη» με συγκεκριμένους στόχους και σχέδια για τις ευρωπαϊκές βιομηχανίες με τις υψηλότερες εκπομπές.

Οι βιομηχανικές εκπομπές είναι οι πιο δύσκολες να αντιμετωπιστούν, επομένως προτείνεται ένας κατάλογος ενεργειών που συμβάλλουν στην απελευθέρωση των βαρέων βιομηχανιών από τη θέση της αναπόφευκτης παραγωγής υψηλών εκπομπών. Εκτός από τις πρακτικές συμβουλές, έχουν αναλυθεί σε βάθος συγκεκριμένες τεχνικές, που αναπτύχθηκαν για ουδέτερες εκπομπές άνθρακα, βασισμένες σε μοντέλα ενός «αλγόριθμου αποσύνθεσης» και μιας «μαθηματικής βελτιστοποίησης». Η πιο σύγχρονη τεχνολογία και τα επιτεύγματά της, όπως η τεχνητή νοημοσύνης και το «διαδίκτυο των πραγμάτων» είναι επίσης τρόποι για να επιτευχθεί η ελαχιστοποίηση των εκπομπών, εφόσον υιοθετηθούν κατάλληλα, ιδίως για τον έλεγχο συστημάτων που εξασφαλίζουν την ποιότητα και την ασφάλεια σε ένα βιομηχανικό περιβάλλον.

Η βιομηχανία διύλισης πετρελαίου ευθύνεται για την πλειονότητα των εκπομπών αερίων θερμοκηπίου, καταλαμβάνοντας την τρίτη θέση μεταξύ των λοιπών βιομηχανιών, με συνολική συμβολή περίπου 5% των συνολικών παγκόσμιων εκπομπών. Είναι αυτονόητο, επομένως, ότι διαδραματίζει κρίσιμο ρόλο τόσο στην αλυσίδα εφοδιασμού ενέργειας όσο και στην κλιματική αλλαγή.

Το διοξείδιο του άνθρακα είναι το κύριο συστατικό που εκπέμπεται από τα διυλιστήρια πετρελαίου, αντιπροσωπεύοντας περίπου το 98% των συνολικών εκπομπών τους. Η μέθοδος που έχει κερδίσει περισσότερη προσοχή για την εξισορρόπησή του είναι η προσέγγιση της «Δέσμευση και Αποθήκευσης Άνθρακα» λόγω των υψηλών ρυθμών δέσμευσης που εξασφαλίζει. Μια άλλη πρόταση είναι η υιοθέτηση τεχνολογιών χαμηλών εκπομπών άνθρακα από εταιρείες διυλιστηρίων πετρελαίου και η παρακολούθησή τους μέσω ενός «Οδικού Χάρτη Ενεργειακής Απόδοσης». Η τελευταία λαμβάνει χώρα σε τρεις φάσεις, τη φάση της «Συλλογής Δεδομένων – Ενδείξεων» από ποικίλες πηγές με υψηλή συμμετοχή εξωτερικών παραγόντων του μακρό-περιβάλλοντος, το στάδιο του «Σχηματισμού μονοπατιού», που αντιπροσωπεύει μια συγκεκριμένη επιλογή και ανάπτυξη επιλογών κατά τη διάρκεια μιας συγκεκριμένης χρονικής περιόδου, που επιλέχθηκε για την επίτευξη μείωσης του άνθρακα και, τέλος, το στάδιο της «Σχεδίασης συμπερασμάτων», που στοχεύει να βοηθήσει στην υπέρβαση των φραγμών της πρώτης φάσης, με τη βοήθεια επιλεγμένων τεχνολογιών στο πλαίσιο της επιλεγμένης «οδού απανθρακοποίησης», καταλήγοντας σε συμπεράσματα που άπτονται διαφόρων θεματικών.

Είναι αναμφίβολο ότι η βιομηχανία διύλισης πετρελαίου αντιμετωπίζει σημαντικές προκλήσεις στην πορεία της απαλλαγής από τον άνθρακα, επομένως έχουν σημειωθεί έξι κατηγορίες για την προσέγγιση της επιθυμητής μείωσης. Μια γκάμα επιλογών που μπορεί να εφαρμοστεί στις περισσότερες περιπτώσεις, όπως η βελτιωμένη ενεργειακή απόδοση, η ανάκτηση απώλειας θερμότητας, η βελτιωμένη απόδοση σχεδιασμού των λειτουργιών μιας μονάδας, η αυξημένη χρήση ανανεώσιμων πηγών ενέργειας, η υιοθέτηση τεχνολογιών χρήσης και αποθήκευσης δέσμευσης άνθρακα και τέλος η υιοθέτηση υδρογόνου με χαμηλές εκπομπές άνθρακα.

Μια πολύ δημοφιλής προσέγγιση είναι η «στάθμιση πολυπλοκότητας των τόνων», βάσει της οποίας προσδιορίζεται η καθαρή κατανάλωση ενέργειας μιας μονάδας εντός ενός διυλιστηρίου. Αυτό είναι σημαντικό σημείο για τη σύγκριση διαφορετικών μονάδων του ίδιου διυλιστηρίου ή μεταξύ περισσότερων διυλιστηρίων, χρησιμοποιώντας την αναλογία των τυπικών εκπομπών διοξειδίου άνθρακα ως τελικές μετρήσεις. Η διαδικασία της απανθρακοποίησης προϋποθέτει την ύπαρξη μιας στρατηγικής απόφασης σχετικά με διάφορους πυλώνες, όπως το σύστημα ανάκτησης απώλειας θερμότητας, τα χρησιμοποιούμενα υλικά, το σύστημα ποτίσματος και τον υπόλοιπο εξοπλισμό που εμπλέκονται τόσο ως υλικά όσο και ως λογισμικά, ώστε η όλη παραγωγή να βασίζεται σε μεθόδους βελτιστοποίησης της δεδομένης τεχνολογίας.

Το ίδιο το υδρογόνο αποτελεί βασικό σημείο διεργασίας, καθώς η κατανάλωσή του συνδέεται σε μεγάλο βαθμό με τις μεθόδους παραγωγής των διυλιστηρίων και αυτός είναι ο λόγος που έχουν αναπτυχθεί τρεις επιλογές για την πραγματοποίηση απανθρακοποίησης από τη χρήσης του. Τα μεγαλύτερα αποτελέσματα παρατηρούνται από την «ολιστικής απανθρακοποίησης», εισάγοντας την τεχνολογία της «δέσμευσης, χρήσης και αποθήκευσης άνθρακα» η οποία περιλαμβάνει τη δέσμευση διοξειδίου άνθρακα από μεγάλες πηγές, το οποίο στη συνέχεια συμπιέζεται και τελικά μεταφέρεται για χρήση σε μια σειρά εφαρμογών, ή εγχέεται σε βαθείς γεωλογικούς σχηματισμούς.

Αναφέρονται επίσης πρόσθετες μεθοδολογίες, οι οποίες έχουν ήδη αναπτυχθεί και χρησιμοποιούνται από κορυφαίες εταιρείες του κλάδου, για παράδειγμα το μοντέλο «Καθαρό Αποτύπωμα Άνθρακα», από την εταιρεία Shell, η οποία έχει αναλάβει σοβαρές δεσμεύσεις για την επίτευξη των παγκόσμιων στόχων του 2050. Αυτό το μοντέλο συνδέεται με τον πλήρη κύκλο ζωής των εκπομπών ενός προϊόντος, συμπεριλαμβανομένης της προμήθειας υλικών, της μεταφοράς τους, της επεξεργασίας για τη δημιουργία προϊόντος, της μεταφοράς στον τελικό χρήστη/πελάτη, αλλά και της χρήσης των απορριμμάτων και των ροών αποβλήτων από το ολόκληρη την παραγωγή.

Δεν είναι μόνο οι πολυεθνικές εταιρείες που έχουν αναλάβει σημαντικές ευθύνες. Η ελληνική εταιρία «HELLENiQ ENERGY» με δραστηριότητα πάνω από 40 χρόνια στον κλάδο, λειτουργεί και επεκτείνεται με το «Όραμα 5050», εναρμονισμένο με τις οδηγίες της Ε.Ε., όντας μέλος της «FuelsEurope», προωθώντας την ιδέα ότι τα διυλιστήρια μπορούν να μετατραπούν σε ενεργειακούς κόμβους για παραγωγή προϊόντων χαμηλών εκπομπών άνθρακα, τα οποία είναι απαραίτητα για μια κλιματικά ουδέτερη οικονομία και κοινωνία. Η εταιρεία του Ομίλου έχει πραγματοποιήσει μια σειρά αλλαγών τα τελευταία 4 χρόνια, ώστε να εκσυγχρονίζει διυλιστήρια και μονάδες παραγωγής, με εξαιρετικό παράδειγμα το διυλιστήριο που βρίσκεται στην περιοχή του Ασπρόπυργου. Από το 2019 έχουν δρομολογηθεί ριζικές αλλαγές όσον αφορά τον εκσυγχρονισμό του διυλιστηρίου και μια καινοτόμο προσέγγιση για την επίτευξη της βιωσιμότητας σε αυτό, με ταυτόχρονη αποτελεσματική μείωση των εκπομπών αερίων του θερμοκηπίου.

ΛΕΞΕΙΣ - ΚΛΕΙΔΙΑ

- Αποτύπωμα άνθρακα
- Οικολογικό αποτύπωμα
- Υπολογισμός αποτυπώματος άνθρακα
- Εκπομπές αερίων του θερμοκηπίου
- Υπολογισμός εκπομπών
- CO_2 & CO_2 ισοδύναμα
- H_2O / CH_4 / N_2O/ O_3/
- Ορυκτά καύσιμα
- Αέρια καύσιμα
- Βιομηχανία υδρογόνου
- Συνθήκη του Kyoto
- Δέσμευση μηδενικών ρύπων
- Στρατηγικές απανθρακοποίησης

- Ουδετεροποίηση άνθρακα
- Στρατηγική χαμηλών ρύπων άνθρακα
- Άμεσες / Έμμεσες εκπομπές
- Παγκόσμια υπερθέρμανση
- Χάρτης ενεργειακής απόδοσης
- Βέλτιστες διαθέσιμες τεχνολογίες
- Ευρωπαϊκός Κλιματικός Νόμος
- Δέσμευση και Αποθήκευση Άνθρακα
- Δέσμευση-Αποθήκευση και Χρησιμοποίηση Άνθρακα
- Ανανεώσιμες πηγές ενέργειας
- Αλγόριθμος αποσύνθεσης
- Το διαδίκτυο «των πραγμάτων», Τεχνητή νοημοσύνη
- Διυλιστήριο πετρελαίου
- Βιομηχανία Πετρελαίου & Φυσικού Αερίου
- Πηγές στατικής καύσης
- Μονάδα καταλυτικής πυρόλυσης
- Δεξαμενές αποθήκευσης
- Μέθοδοι μείωσης
- Προσέγγιση σταθμισμένης πολυπλοκότητας σε τόνους
- Τεχνολογία καύσης
- Μοντέλο καθαρού αποτυπώματος άνθρακα
- Αλυσίδα εφοδιασμού πετρελαίου
- Ελληνική Ενέργεια

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CHAPTER 1: INTRODUCTION

1.1Background and motivation for the work

The refining sector plays a crucial role in meeting the rising global demand for energy. However, carbon dioxide (CO2) emissions from refining are a major contributor to greenhouse gas emissions. There is an urgent need to reduce the carbon footprint of the refining industry due to mounting concerns about climate change and efforts to mitigate its effects.

Refineries are complex machinery that transform petroleum oil into gasoline, diesel, and petrochemicals. The refining process involves numerous energy-intensive stages, such as distillation, cracking, and reforming, which together consume a substantial amount of fossil fuels and generate a substantial amount of carbon dioxide emissions. Not only are these emissions detrimental to the environment and the health of local residents, but they also contribute to global warming.

The environmental issues afflicting the refining industry inspired this Master's thesis. There is a moral and financial imperative to reduce the environmental impact of refining activities. In a carbon-constrained future, businesses that continue to implement sustainable practices while governments around the world institute more restrictions and policies to reduce greenhouse gas emissions will be best positioned for success.

In addition, as consumer awareness and preferences increase, the market demand for low-carbon and environmentally beneficial products grows. Businesses that can provide more eco-friendly fuels while minimizing their environmental impact will have a competitive advantage in the marketplace. This dissertation is an attempt to reduce carbon emissions of the refining industry and contribute to larger goals of sustainable development and corporate social responsibility.

In addition, recent technological and engineering advancements have opened up intriguing avenues for addressing the issue of refining's carbon footprint. There are a plethora of emission reduction strategies, ranging from adjustments to existing processes and improvements to energy efficiency to novel approaches such as carbon capture and storage (CCS). However, extensive research is required to determine which methods will be the most effective and feasible for reducing the carbon footprint of the refining industry.

This dissertation's findings and recommendations will assist the refining industry, legislators, and academics in developing and implementing effective carbon footprint reduction strategies. In addition to promoting environmentally friendly procedures and supporting worldwide efforts toward a low-carbon future, this initiative will contribute to the corpus of knowledge in oil and gas systems and process engineering.

This study aims to address the pressing issue of reducing the refining industry's carbon footprint by investigating novel approaches and proposing measures that could accelerate the industry's transition to sustainable practices.

CHAPTER 2: DEFINITION OF CARBON FOOTPRINT

2.1. Carbon Footprint term

Two words that have received a lot of attention and assumed greater relevance during the last several decades are "carbon footprint" and "greenhouse gas emissions" (GHE). Since a carbon footprint is a relative estimate of the quantity of CO2 released into the atmosphere during the life lifespan of a product or activity, there is a cause-and-effect relationship between the two. Carbon dioxide (CO2), Water vapor (H2O), methane (CH4), ozone (O3), nitrous oxide (N2O), and freon are the primary greenhouse gas emissions responsible for global warming. However, carbon dioxide (CO2) is the primary contributor to these emissions, and as a result, there is now widespread agreement to express and regulate atmospheric CO2 concentrations using the phrase "carbon footprint" (Ding et al., 2009). It is measured in terms of the amount of carbon dioxide (CO2) released into the atmosphere; this implies that emissions of other greenhouse gases (such as methane, nitrous oxide, and fluorinated gases) are converted to CO2-eq to account for their potential impact on climate change. It is often determined by looking at both the process's direct and indirect emissions. For this reason, companies, consumers, and even politicians pay close attention to it; it is not only a technical or scientific phrase but an indication of the effect of greenhouse gas emissions from goods and services (Wiedmann, T., Minx, J., 2008). Modern investors "control" their goods' carbon footprints since they are a measure of investment risk and a symbol of long-term, environmentally responsible investments. Global marketplaces are making an effort to provide customers with items that have been carbon tagged, and business managers are taking notice. Carbon prices, lowering emissions trading limits, tax penalties and incentives, enforced environmental standards, and greater public investment are all instruments legislators are employing to shape their legislative efforts and agenda in this direction. It is instructive that each country's average individual carbon footprint is given, and it is even more encouraging that this footprint can be estimated using data from many indicator categories, such as emissions from homes, transportation, food, and consumer goods. Figure 1 shows global major economies' projected 2020 CO2 emissions in tons represented in billions of dollars, and it is apparent that China's emissions are higher than those of all developed nations put together. For two years in a row, China was shown to be the greatest emitter in a research (Rhodium Group, 2021). China's emissions in 2019 were only 0.8% higher than the global total. As China's emissions rose and those of the other nations declined by just over 10% in 2020, the disparity widened to almost 13%.

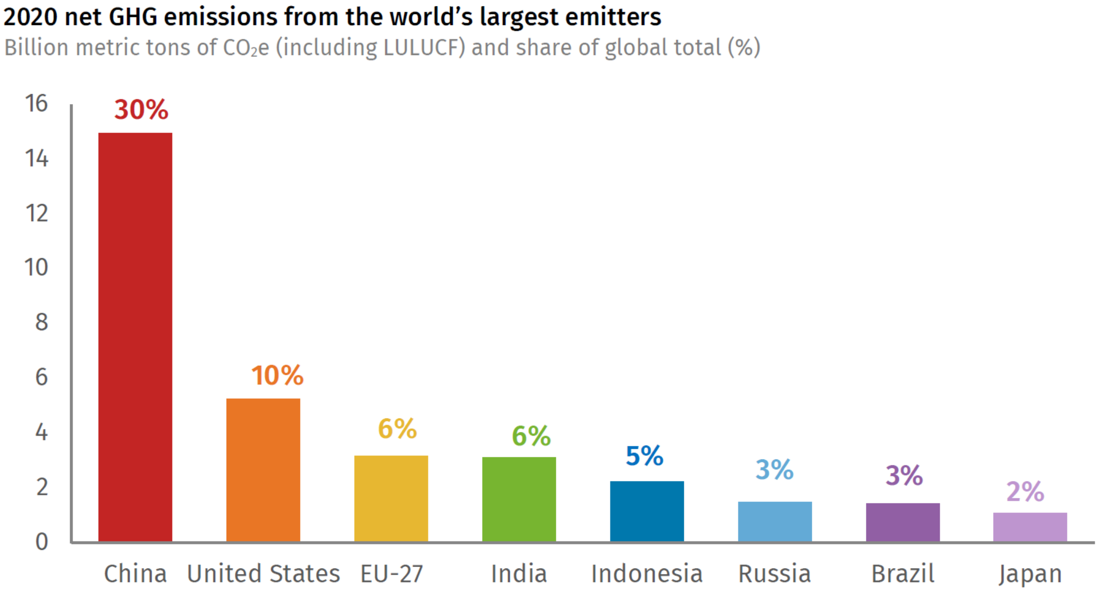


Figure 1. 2020 net greenhouse gas emissions from world's largest emitters (Rhodium Group, 2021).

Figure 2: Global Manmade Greenhouse Gas Emissions by Sector - World Resources Institute, 2017 shows clear conclusions regarding primary gas emissions, including heat and electricity (31%), agriculture (11%), transport (15%), forestry (6%), and manufacturing (12%), which are directly derived from the results of the Climate Analysis Indicators Tool. Seventy-two per cent of all emissions come from the use of energy in any kind of manufacturing. Figure 1's data backs this up, showing that China is the leading emitter due to its enormous production and consumption of both power and heat.

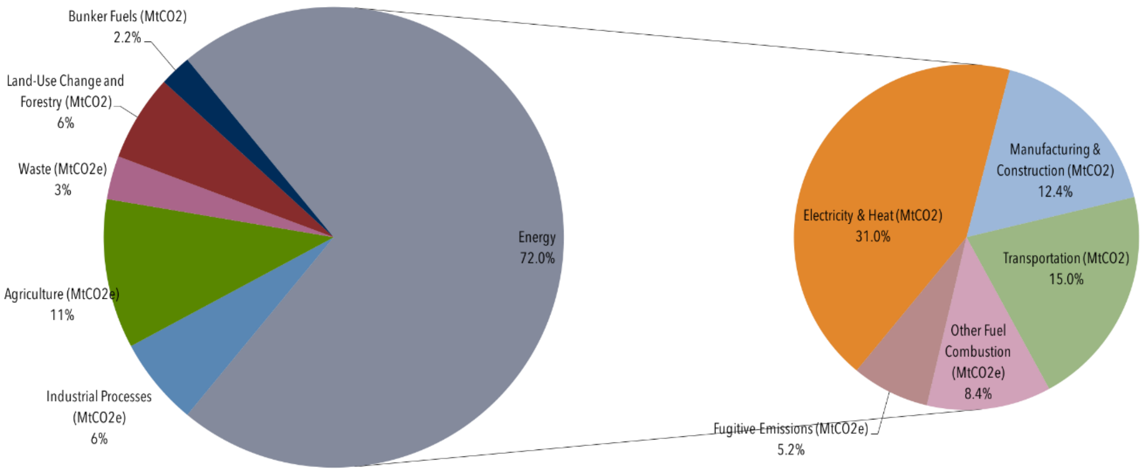


Figure 2. Global Manmade Greenhouse Gas Emissions by Sector (World Resources Institute, 2017).

2.2. Kyoto Protocol

In the 1990s, the United Nations started discussing carbon emissions at conferences in an effort to minimize emissions. The UN Framework Convention on Climate Change was established in 1992 at the United Nations Summit on Environment and Development. The Kyoto Protocol puts into action the United Nations Framework Conventions on Climate Change by obligating industrialized and developed nations to cut their emissions of greenhouse gases according to predetermined goals. As an important commitment under the concept of "common but distinguished responsibilities and respective capabilities," it binds developed countries, who are primarily liable for the current elevated levels of emissions of greenhouse gases in the atmosphere. This is in line with the tenets and regulations of the International Convention and its annex-based structure. The agreement also mandates frequent reporting and the implementation of policies and actions to reduce emissions in these nations. It's the first global pact to limit emissions of greenhouse gases. At three December 1997 sessions of the signatory nations to the United Nations Framework Convention on Climate Change, the Kyoto Agreement on Climate Change was considered and developed. The avoidance of severe climate change that risks the survival of humanity is the driving force behind this plan to stabilize atmospheric emissions. The treaty establishes legally obligatory objectives for the reduction of carbon emissions for 37 nations, both developed and industrialized, as well as the European Union. These goals add up to a median emission reduction of 5% below 1990 levels from 2008-2012. The original commitment time for the Doha Amendment expired in 2012, but it was renewed for a second term in Doha, Qatar, that would run from 2013 to 2020. According to the UN Climate Change FAQ (What is the Kyoto Protocol?), on October 28, 2020, 147 States have expressed support for the Doha Amendment going into effect and acknowledging its accomplishments., which you can get at https://unfccc.int/kyoto_protocol.

2.3. Net Zero commitment

It sparked another informal worldwide commitment, proclaimed in the form of a global objective, the "net zero by 2030," a declaration that was only recently modified and expanded to the new time frame, the "net zero by 2050." This suggests that economies throughout the globe will not be able to meet the original target by 2030, and as a result, there has been an increase in the number of announcements promising to reach zero emissions by the end of the century. However, the pledges by governments fall short of what is required to bring global energy-related CO2 emissions to net zero by 2050 (International Energy Agency, 2021, A roadmap for the global energy sector, Net Zero by 2050, available at: https://www.iea.org/reports/net-zero-by-2050) and give the world a fair chance of limiting the global temperature rise to 1.5 °C. Both. Reducing emissions wherever feasible and offsetting what can't be eliminated with verifiable offsets, with an emphasis on carbon removal projects, is how we get to net zero emissions for Scope 1, Scope 2, and the vast majority of the applicable emissions under Scope 3 (see below). Since most emissions arise from business activities, it is crucial that organizations employing a net-zero emissions strategy use scientifically validated goals to achieve their emission reduction strategy and employ verified standards for offsets for carbon or other offset goods authorized by relevant highly skilled governmental or collaborative entities, with a focus on carbon removals. Achieving the transition to a net zero energy system by 2050 while guaranteeing reliable and inexpensive energy supplies, providing universal energy access, and facilitating vigorous economic development is a high-stakes wager (International Energy Agency, 2021, Net Zero by 2050- flagship study). Many businesses have responded to this need by adopting it as part of their corporate strategy or by aligning shareholder interests with it, seeing it as both a necessity and an opportunity. One may infer the direction most sectors will go based on their apparent emphasis on carbon footprint.

2.4 Carbon footprint calculation

When determining a carbon footprint, it is important to consider the limits of the process and choose the relevant emissions for analysis. The carbon footprint technique is one way in which a company may determine its GHG emissions. A company's impact on the environment may be impacted in both direct and indirect ways, such as via the usage of automobiles, the consumption of energy inside buildings, the means of transport and travel for work of employees, the purchase of products and services, and so on. "(Awanthi and Navaratne, 2018)" Despite its popularity and ease of use, the carbon footprint has been criticized for simplifying environmental impacts by focusing just on greenhouse gas emissions while ignoring, for instance, damaging emissions to water and land. Therefore, it is said, it does not provide a reliable indicator of a company's long-term viability. Weidema et al. (2008); Laurent et al. (2012). There is more than one method for determining a product's carbon footprint. It is for this reason that carbon footprint estimates provide varying findings (Ng et al., 2013; Padgett et al., 2008; Pandey et al., 2011) due to differences in system boundaries and other methodological choices. This is also true for carbon footprint estimates that are less typical at organizations. To better structure its carbon footprint analysis, a company should make an effort to account for all immediate emissions within one of three gradated levels, or "Scopes" (see Figure 3, Emissions Scope Levels, Anthesis Group, 2023) of emissions. Emissions from sources that the reported organization controls or owns are more narrowly defined as Scope 1. In the manufacturing industry, for instance, direct emissions include production odors. Emissions that come with the bought energy are considered Scope 2 emissions. Greenhouse gas emissions are caused by the party using the energy and occur at the plant where the power, steam, heating and cooling, is generated. Scope 3 is the third and final phase, and it includes all emissions that do not fall under Scope 2. These are emissions that come from outside of the reporting party's ownership or direct control. However, they relate to how the company functions. Supply chain issues often arise when a firm relies on outside parties to complete essential functions. Scope 3 emissions account for the majority of greenhouse gas emissions in several sectors, which is a particularly noteworthy finding considering that most contemporary firms do not control the complete value chain of the products or services they provide. Instead, they rely on outsourcing services for a wide range of projects. Scopes 1 and 2 are significantly easier to compute than Scope 3, thus it's preferable to tackle the computation as a whole.

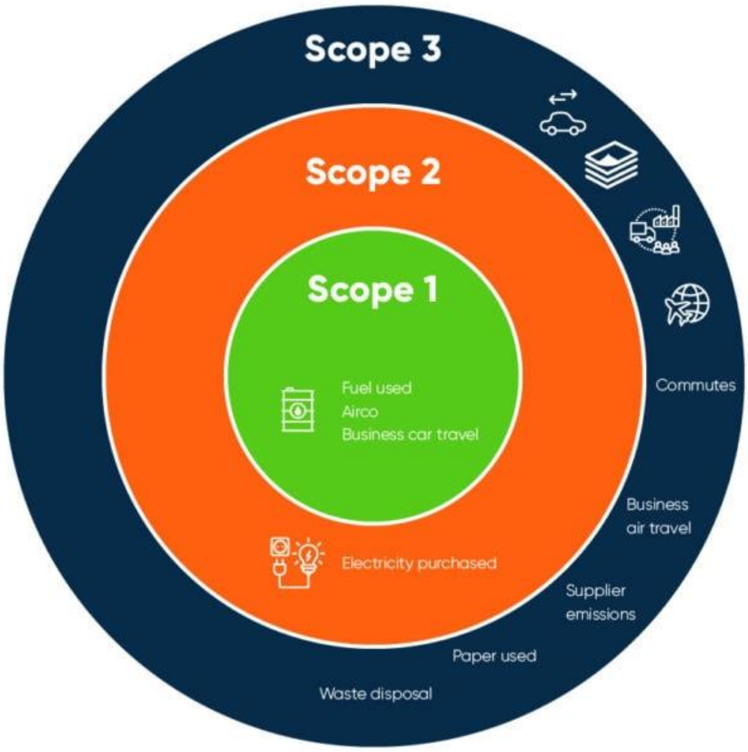


Figure 3. Levels of Scopes of emissions (Anthesis Group, 2023)

Traditional process-LCA, environmentally extended input-output assessment (EEIO), and hybrid-LCA, additionally referred to as the hybrid economic input-output-based look at (EIO) (Onat et al., 2014) are the three ways to calculate an organization's carbon footprint, as stated by Nakamura and Nankai (2016). While the input-output model looks at the relationship between financial expenditures and environmental consequences from the top down, the LCA process takes a bottom-up approach by calculating emissions at each level of a system (Kitzes, 2013). The primary distinction between the two methods is that process-based techniques do not take into account monetary flows such those associated with bought commodities (Suh et al., 2004). However, when comparing goods and services within the same sector, EEIO falls short (Kitzes, 2013; Suh et al., 2004), despite its potential to facilitate replication and comparability across firms. The purpose of the hybrid EEIO-LCA is to capitalize on the benefits of both the process-LCA and the EEIO analysis (Crawford et al., 2017).

2.5 Categories of emissions

In order to identify the origins of greenhouse gas emissions, the emissions are divided into three groups, or "Scopes." Scope 1 emissions refer specifically to those from facilities under an organization's direct management. Within this Scope, we address emissions caused by the on-site combustion of fuel. Emissions from particular sources, such as cars or gas stoves, would be considered Scope 1 pollution. The reporting company's use of externally generated power, steam, heating, and cooling falls within Scope 2's purview of indirect emissions. All additional indirect emissions across the value chain of a corporation fall under Scope 3. Scope's three emissions fall under 15 quantifiable areas, including as business travel and staff transportation. Calculating data for additional Scope 3 categories, such as bought products and services or the end of life treatment of sold items, may be difficult and may include complicated modeling, inputs, and assumptions. Not all fifteen groups will apply to a business, depending on its field of operation. Figure 4 "Greenhouse Protocol - Carbon Accounting Categories" (Brightest, Inc. 2022) depicts the aforementioned.

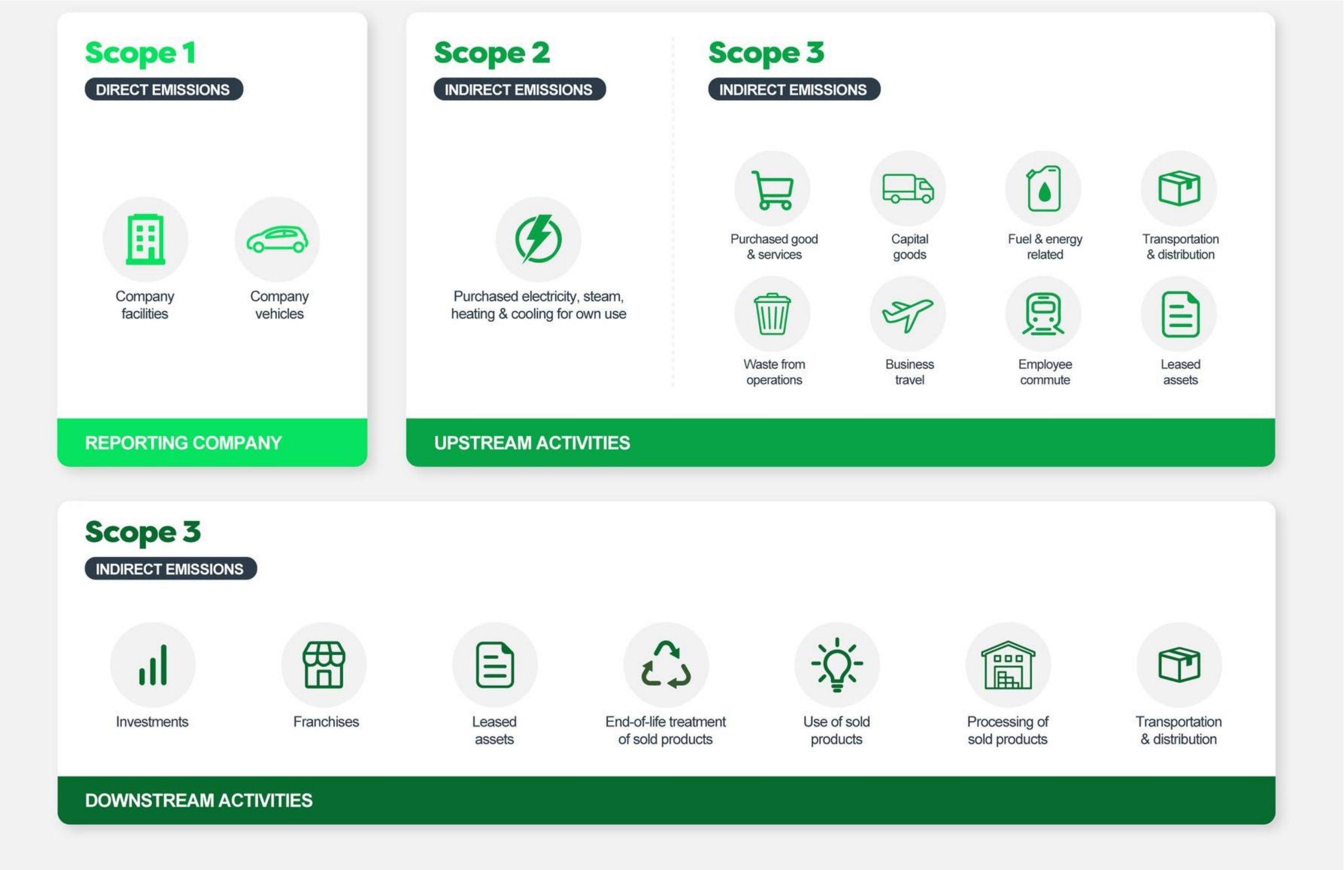


Figure 4. Greenhouse Protocol – Carbon Accounting Categories (Brightest, Inc. 2022).

Why should a company bother to track its Scope 3 emissions has been a hot topic recently. The response has been that there are several advantages to keeping track of these pollutants. The bulk of a company's greenhouse gas emissions and potential to save costs lay outside of the company's activities. The following are only some of the many benefits that businesses have seen as a result of monitoring Scope 3 emissions (Carbon Trust, Briefing: What are Scope 3 emissions, accessible at https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/briefing-what-are-scope-3-emissions).

- Determine the potential resource and energy hazards in their supply chain's emission hotspots.
- Locate areas where they can save money and energy in the supply chain and leisure pursuits.
- Evaluate their suppliers' sustainability efforts and identify industry leaders.
- Involve vendors and help them with environmental efforts.
- Raise the already high efficiency ratings of their offerings.

Motivate and encourage workers to cut down on emissions from business trips and commuting.

2.6. Footprint Family Associations

Although the term "carbon footprint" may sound more modern and involved than "ecological footprint," both concepts have their origins in the early 1990s and were developed at the University of British Columbia by Canadian ecological scientist William Rees and the born in Switzerland regional organizer Mathis Wackernagel. A population's or activity's ecological footprint is the entire amount of land that supports it. Water consumption and the amount of land devoted to agricultural purposes are two examples of environmental effects (Monfreda et al., 2004; Wackernagel et al., 1999b). The ecological footprint is a restrictive metric because it emphasizes the whole strain that human resource use puts on the planet's natural assets. Each flow is stated in terms of the yearly area need for the provision of the corresponding resource flow, rather than in terms of the quantity of material transferred every year. To rephrase, an ecological footprint is a quantitative estimate of the amount of natural resources that have been used and those that remain. It assesses the environmental assets that a single people or product needs in order to generate the resources that it consumes and to collect its waste, particularly carbon emissions, and it encompasses all the productive regions for which a community, person, or product competes. The carbon footprint is not measured in square feet despite the name. Greenhouse gases are measured in mass units; there is no practical way to convert this to an area unit. For the latter to occur, several assumptions would need to be made, all of which would increase the room for error and the magnitude of the estimated carbon footprint (A. Galli et al., 2012). Carbon footprint is measured in kilograms of carbon dioxide (kg CO2), or in kilograms of carbon dioxide equivalents (kg CO2-e) if additional greenhouse gases are included. The global warming impacts of various GHGs are similar and additive since they are computed by dividing the real mass of a gas by the potential for global warming factor for this gas. According to the EU project, the study takes into account all six of the greenhouse gases included in the Kyoto Protocol: CO2, CH4, N2O, HFC, PFC, and SF6. As a consumption-based measure of freshwater usage, water footprint was developed in response to a gap in the literature (Hoekstra, 2003). Because it takes into consideration the acquisition of natural resources in terms of the water quantities needed for human consumption, it is related to the simulated water idea (Allan, 1998). Like the carbon footprint, the water footprint considers both the use and production of water. The primary goal of this idea is to show how the global commerce and the management of water resources are inextricably linked. To emphasize the significance of consumption by humans and global aspects in effective water governance, this term has been introduced into the field of water management science (Hoekstra, 2009).

Finally, integrated ecosystem approaches are more likely to inform leaders around the world when it comes to managing the planet's ecological assets (Best et al., 2008). This is because they allow for the comforting of multiple issues at once and assist in preventing additional expenditures or unintentionally undoing advancements in one sector by disregarding into consideration both the immediate and long-term implications of measures in other sectors (Robinso).

CHAPTER 3: KEY DRIVERS FOR REDUCING CARBON FOOTPRINT

3.1 Introduction

Businesses, like their customers, tend to stick to what they know works. That's why it's so hard to get people to alter their ways of behaving. Nonetheless, 'out of everyone's comfort zone' is where we need to be in order to reach the objective of carbon neutrality by 2050 (European Parliament, 2023, https://www.europarl.europa.eu/). While the benefits of technology, encouraging government regulations, and public opinion are all converging to get us closer to this goal, the vast majority of people are only beginning to incorporate these elements into their daily lives. Demand creation for "low carbon" or "no carbo" items as an alternative to those with a massive carbon footprint is crucial to making any forward. According to Climate Action (2020) (https://www.climateaction.org/), there are four primary factors that might stimulate this kind of demand.

<u>Identifying and promoting carbon-light products</u>

Market research shows that the cost of decarbonization to consumers is negligible in many industries. Given these subtle distinctions, market expansion might benefit from targeting eco-conscious buyers who don't mind paying a little extra for a more moral product. A 'low carbon' and 'carbon neutral' designation for the whole manufacturing chain would differentiate goods and streamline the sourcing process. Labels are used in procurement to help find companies that have met certain standards for reducing their carbon footprint, and this certification may also give consumers confidence in the product's environmental credentials.

<u>Raising Efficiency Standards for Energy Use</u>

The numerical indicators that have shown to be most helpful in encouraging the adoption of energy-efficient solutions are energy-efficiency standards and ratings. For instance, the European Commission (https://energy.ec.europa.eu/) cites the "EU's Regulation of Energy Efficiency (2018/2002)" (as part of the European Green Deal and in conjunction with other EU climate and energy rules) as establishing regulations and responsibilities for achieving the EU's 2020 and 2030 efficiency in energy targets. The directive went into effect in December 2018, and Member States were required to adopt it into their own legislation by June 25, 2020. To ensure that energy efficiency and other objectives are met by 2030 (European Climate Initiative EUKI, https://www.euki.de/), Member States must create integrated 10-year national energy and climate plans (NECPs) in accordance with the Governance Regulation 2018/1999. There is room to grow the adoption of such standards in underdeveloped markets and industries, but first, policymakers must facilitate, rather than stifle, innovation by not telling consumers which technologies they are allowed to use.

Reducing Obstacles to Trade

The importance of economic globalization and trade liberalization cannot be overstated when discussing the link between international commerce and carbon emissions (Front. Energy Res, 2021, https://www.frontiersin.org/). This makes it much simpler to generate reasonable recommendations for reducing carbon emissions across the world. The ability to monitor and choose carbon-neutral items is crucial to increasing demand for them. Global markets for green energy technologies, such as solar and wind, are certain to be formed and to lead the future if international commerce is more open and less controlled. Every international and provincial bilateral trade agreement has to include measures to make trading easier. As initiatives like the G20 Commission on Financial Disclosures related to Climate Change highlight, money is another crucial enabler. Committee members are committed to identifying and favoring responsible business conduct and carbon neutrality via their investments (Climate Action, 2020, https://www.climateaction.org/), thus they've created a framework for such disclosure. Throughout the course of global economic integration, countries may make concerted efforts on general strategy and coordination in order to encourage the best allocation of their resources and minimize carbon emissions, taking into account their individual stages of development and comparative advantages. Since two major issues—global carbon emissions and global trade—have recently emerged, distinguishing between them is difficult. To begin, determining who exactly is to blame for carbon emissions during product transport is difficult since the responsibility is often disputed. Second, when this policy will lead to increased production costs for firms as a consequence of the implementation of low-carbon technologies and replacement of existing equipment, further "green barriers" and a tax on carbon competitiveness may damage the free trade system. Most industrialized nations may use carbon tariffs and/or adopt environmental protection rules to establish impediments to international commerce (Front. Energy Res, 2021, https://www.frontiersin.org/). This is done to safeguard domestic firms. The European Union has already done this by instituting a "carbon border adjustment mechanism" that charges foreign products as part of a gradual emission reduction process, creating de facto trade barriers and raising prices for exporting nations (Chu, et al., 2021).

Carbon pricing's place in the equation

In order to reduce emissions of carbon dioxide (CO2) along with other greenhouse gases, carbon pricing has been proposed as a legislative measure. The purpose of carbon pricing is to shift the burden of these expenses on those who cause them (MIT Climate Portal, 2022; https://climate.mit.edu/). As a result of having to pay for every ton of carbon dioxide (CO2) they release, producers as well as consumers are incentivized to use less carbon-intensive energy sources and increase their energy efficiency. A carbon tax & a system of cap-and-trade are the two most common methods for carbon pricing.

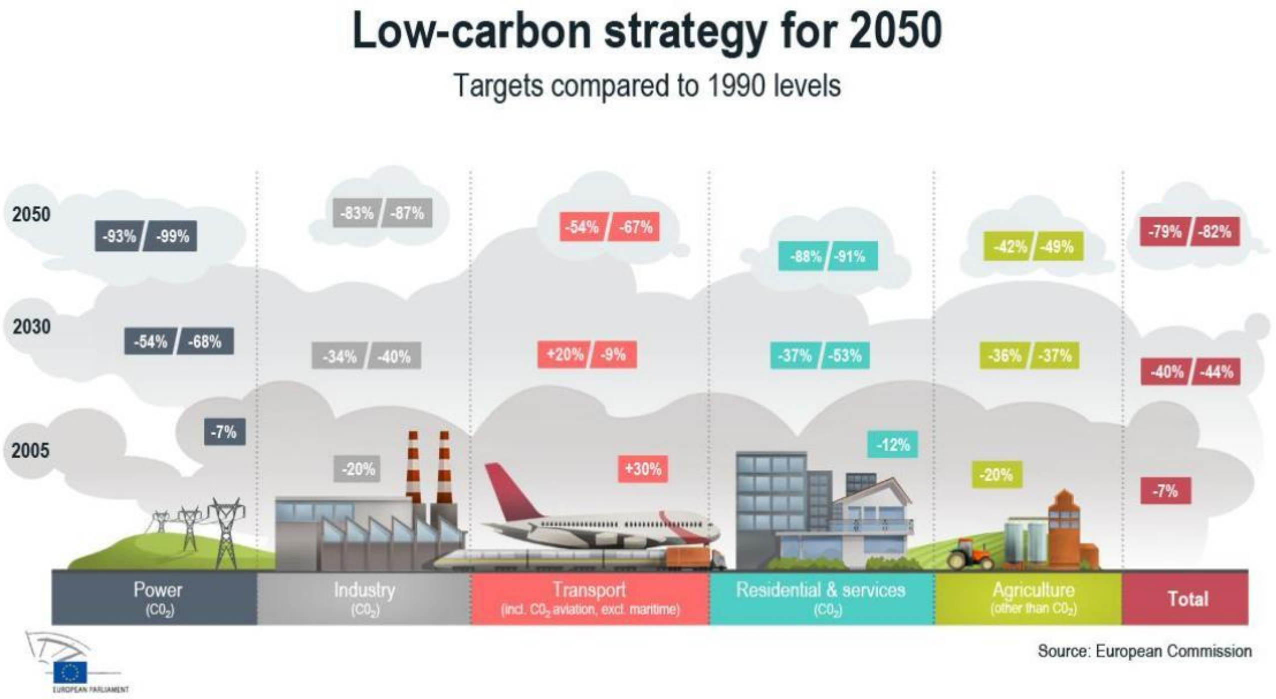
A tax on carbon emissions that would be applied on a per-ton basis. Emissions reduction is contingent on adopters' willingness to modify their behavior in response to the introduction of a levy.

A system where the entire quantity of emissions that may be emitted is agreed upon or determined in advance is called a system of cap-and-trade (or emissions trading system). The government then hands out a restricted amount of emissions allows, either freely to polluters or by auction. The emitter must be in possession of a valid permit for every ton of emissions discharged. Emitters may exchange permits with one another; those who are unable to reduce their emissions at a reasonable cost must purchase licenses from those who are able to. After then, the price of carbon is determined by the market for permits.

The International Energy Agency, the World Economic Forum, and the United Nations Secretary-General all support energy taxation strategies and carbon pricing as a means of giving businesses an incentive to modify their production methods and opt for lower carbon products.

3.2 The European Climate Law

Companies, on the other hand, are under a lot of pressure, and in some instances, like refineries, are even required, to include carbon footprint reduction initiatives as part of their operations and leadership framework. The "intensification of regulation" itself, "corporate image damages," and "evolution of environmental standards as foundation of their competitiveness" are the driving forces behind these choices. For further clarification, it is worth noting that the European Climate Law, which was released in the Official Journal on July 9, 2021, and came into force on July 20, 2021, takes into account the goal of climate-neutralization through 2050, with a reference additionally to the first came across target of decreasing the net greenhouses gas emissions by a minimum of 54 percent by 2030, in comparison with the levels of 1990 (European Commission, Climate Action, https://climate.ec.europa.eu/). As shown in Figure 5, the "Roadmap for moving to a competitive low carbon economy in 2050" (European Parliament, 2012) lays out plans and targets for the power generation, industry, transportation, buildings, construction, and agriculture sectors, which are responsible for the bulk of Europe's emissions. The European Union and its member countries have pledged to adopt the necessary measures at both the European and national levels to achieve the goal, with a particular focus on fostering justice and solidarity. Although it has the name "law," the European Climate Law serves more as guidance, since it will not be finalized and adopted until after a high-level public meeting on the topic is held on January 28, 2020. The general public was given a chance to voice its opinion on the proposed legislation.



Source: European Commission

Figure 5. Roadmap for moving to a competitive low carbon economy in 2050 (European Parliament, 2012).

3.3. Reduction of industrial emissions

One-third of all energy used in the world is used in the industrial sector because of how energy-intensive it is. Around 70% of this energy comes from fossil fuels, and 40% of all CO2 emissions come from industry (Griffiths S., Sovacooj B., Kim M., Bazilian M., Uratani M., "Decarbonizing the oil refining industry: A systematic review of sociotechnical systems, technological innovations, and policy options," Energy Research & Social Science 2022). Energy consumption and CO2 emissions have continued to rise dramatically despite efforts to improve energy intensity (Md. Mahfuzar Rahman Chowdhury. "chapter 4 Reduction of Carbon Intensity", IGI Global, 2019). Reducing industrial emissions will require a concerted and long-term effort, one that will be difficult to monitor and regulate. Grantham Institute's Briefing Paper: "Reducing CO2 emissions from heavy industry: a review of technologies and considerations for policy makers" (2012), https://www.imperial.ac.uk/, recommends several steps to be taken in order to help businesses reduce their carbon footprint.

a) Maximization of energy efficiency with the use of Best Available Technologies

One of the greatest ways to get fast results in cutting down on greenhouse gas emissions is to put that technology and those best practices to use. In this context, "best available technologies" refer to using:

- In order to stay up with the rapid pace of technological development, it is necessary to spend heavily in process-specific technologies such as enhanced process designs, heat recovery, and integration choices.
- Systems and machinery that use energy-efficient motors; steam or other installations of power and heating units; and other similar interdisciplinary technologies. These techniques may be used to a broad variety of operations without significant added expenses.
- Technologies that are both broadly applicable and narrowly tailored to reduce greenhouse gas emissions, with a primary emphasis on carbon dioxide (CO_2).

b) Fuel switching to low carbon energy sources

By switching from fossil fuels to low-carbon energy, we can drastically reduce our contribution to global warming. By powering fossil fuel plants with low-carbon hydrogen and ammonia, for instance (International Energy Agency, The Role of Low-Carbon Fuels in the Clean Energy Transitions of the Power Sector, https://www.iea.org/), electricity security can be better maintained during clean energy transitions. Combusting large percentages of carbon-neutral energy sources utilizing quickly improving technology like these offers one additional instrument for decarbonizing:

- The high temperatures within industrial reactors make co-firing of biofuels and wastes a more "environmentally friendly" way to minimize fossil fuel use. When biomass is used as a partial replacement fuel in high-efficiency coal boilers, it produces electricity at a cheap cost while also being environmentally friendly (National Renewable Energy Laboratory, Biomass Cofiring: A Renewable Alternative for Utilities,2000, https://www.nrel.gov/). Burning fuel made from MSW is an attractive low-cost retrofitting strategy for coal power facilities, and it has the additional advantage of decreasing MSW disposal in landfills. co-combustion of waste-derived fuel and coal (IntechOpen, Municipal Solid Waste Cofiring in Coal Power Plants: Combustion Performance, 2016, https://www.intechopen.com/).

- Fuel and food sources To ensure the long-term viability of companies, it is crucial that they make the transfer from natural gas and petroleum to alternative, mostly bio-based feedstocks. By developing innovative energy-efficient procedures to make use of these organic and other feedstocks, they will be able to manufacture products using resources that generate much less carbon emissions. American Chemistry Society, Sustainable U.S. Manufacturing: Chemical and Allied Industries, https://www.acs.org/), states that "the transition will create an entirely new manufacturing industry of feedstock supply, preparation, and transformation, which will re-purpose idled or less-competitive manufacturing facilities and revitalize many economies."

c) Acceleration research for CO_2 Capture and Storage plants (CCS)

To satisfy the rising need for decarbonization, businesses across sectors are making investments in carbon capture and retention systems. Capturing carbon dioxide (CO2) from big point sources like fossil fuel or biomass power plants and factories is the goal of CCS. Carbon dioxide (CO2) can be extracted from the air, compressed, and shipped, trucked, or transported by any number of other methods to wherever it is needed, or it can be injected into deep geological formations to be permanently stored (State of Green, Explaining carbon capture, utilisation, and storage, 2022, https://stateofgreen.com/). Carbon removal, or the concept of "negative emissions," may be built upon the foundation provided by such technologies, whether the CO2 in question originates from biological processes or the atmosphere itself. Since establishing consistent and targeted investment and R&D leads to reductions in emissions and industrial costs, one can see how crucial this is. In order to achieve this goal, we will need a dramatic shift in approach and widespread international cooperation.

d) Product's re-design to facilitate reuse and recycling

To satisfy the rising need for decarbonization, businesses across sectors are making investments in carbon capture and retention systems. Capturing carbon dioxide (CO2) from big point sources like fossil fuel or biomass power plants and factories is the goal of CCS. Carbon dioxide (CO2) can be extracted from the air, compressed, and shipped, trucked, or transported by any number of other methods to wherever it is needed, or it can be injected into deep geological formations to be permanently stored (State of Green, Explaining carbon capture, utilisation, and storage, 2022, https://stateofgreen.com/). Carbon removal, or the concept of "negative emissions," may be built upon the foundation provided by such technologies, whether the CO2 in question originates from biological processes or the atmosphere itself. Since establishing consistent and targeted investment and R&D leads to reductions in emissions and industrial costs, one can see how crucial this is. In order to achieve this goal, we will need a dramatic shift in approach and widespread international cooperation.

3.4 Carbon and footprint constrained energy planning

This heightened awareness of climate change has sparked a renewed focus on the potential of flow-carbon energy technology. In addition to combustion-based technologies with decreased carbon footprints thanks to either downstream or upstream carbon sequestration, these technologies also include non-combustion sources with low carbon footprints by means, such as renewable energy sources like wind, solar, or nuclear. There is a need for more study into the establishment of different methods to optimize the implementation of suitable technologies, with an eye toward meeting environmental goals while also taking into account all relevant technological and economic constraints, as each of the aforementioned options retains its own set of benefits and drawbacks. Land use, water consumption, and nutrient cycle imbalance are also having major global impacts (Foo D., Tan R., "A review on process integration techniques for carbon emissions and environmental footprint problems", Process Safety and Environmental Protection, 2016). Decision-making is aided by human factor systems, and hence a "footprint" metric has been developed to quantify this influence. One frequent definition of energy planning is the act of creating long-term strategies that will direct the evolution of an energy system at any scale (from the household to the country to the world). Electric utilities and oil and gas producers are two examples of significant energy corporations that engage in energy planning (Energy Efficiency, 2013). It is typically carried out using holistic strategies that take into account the availability of energy supplies and the significance of energy efficiency to decrease demands, while always reflecting the results of population growth, and with input from various stakeholders including government agencies and partners, companies, scholars, investigators, and other groups of interest.

Energy planning has played a crucial role in establishing the rules that govern the energy industry, including the construction of power plants and the pricing of fuels. Deregulation of energy markets in many countries over the last several decades has diminished the importance of energy planning and shifted responsibility for making energy-related choices from governments to the private sector. There is little question that this has increased competition within the energy industry, but there is less proof that it has resulted in reduced energy costs for consumers. Large, very successful corporations have amassed a lot of clout since deregulation and are now acting as the de facto "setter of price" in their industries. Today, however, this pattern seems to be breaking down as people become more aware of the negative effects of energy use and production on the environment, especially in light of the fact that greenhouse gas emissions from the world's energy systems are a major contributor to the looming crisis of climate change.

Communities that are interested in ensuring their own energy independence and using best practices in planning should focus on sustainable energy planning. To achieve an environmentally friendly energy sector, policymakers must strike a delicate balance between the generation of energy and minimal environmental repercussions, while simultaneously allowing for the mobilization of social and economic activity at all levels of production. As a result, there has been a lot of focus on techniques and tools for assisted decision making, with the goal of providing a helpful framework for a wide range of choices to be made in the face of ambiguity. As a result, it is clear that the representation and sustainable design are prioritized in addition to the optimization method chosen and the variety of evaluation indicators considered (Smith R. and Ruiz-Mercado G., A method for decision making using sustainability indicators. Clean Technologies and Environmental Policy., 2013).

Knowledge of previous and current energy usage as well as forecasts of future demand is essential for energy planning. Energy costs have a substantial impact on these usage habits. Therefore, the relative and absolute energy prices should be taken into account in any demand analysis or demand forecast, as they influence not only the decision between different energy sources, but also the decision between using energy and other inputs, such as capital and labor, or between using energy as well as non energy absorbing activities (European Central Bank,2022, https://www.ecb.europa.eu/). This statement addresses the fourth primary factor in cutting down on carbon emissions, and it refers back to section 3.1, where it is explained that changes in energy prices can have a significant impact on consumers' behavior, particularly in the long run; however, this is not a solution that can bring about the neutral carbon levels that are ideally sought.

An example source-demand diagram for the "carbon-constrained energy planning" issue is presented in Figure 6. Finding the bare minimum of carbon-free and low-carbon sources of energy that can meet demand is the goal. According to Foo (2012), this model representation assumes that a precious external new resource is used as little as possible.

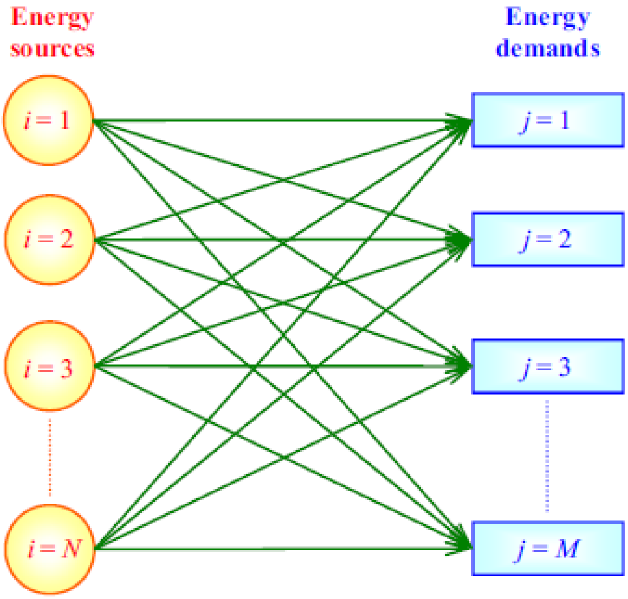


Figure 6. Source-demand representation for energy planning (Lee et al., 2009).

3.6 The way to net zero through “Artificial Intelligence” and “Internet of Things”.

The effective reduction of greenhouse gas emissions is not the exclusive domain of conventional methods alone. Today, most technological advances serve as a resource for a wide range of improvements and operations that are of interest on several scales, from the national to the personal to the organizational. We are living through the 4th industrial revolution, or "Industry 4", which is changing the nature of production as we know it. Because automation and information processing in manufacturing processes have altered industry control systems, the fourth industrial revolution, or Industry 4.0, has emerged as a byproduct of the Internet of Things (IoT) era. There are several benefits to adopting systems that regulate production processes across a network, beyond only the ability to generate revenue and implement real-time improvements. These efficiencies not only help the environment and speed up a company's path to sustainability, but they also boost profit margins in manufacturing.

Developments in areas such as machnie learning and artificial intelligence (AI) are primarily responsible for this seismic shift. "Smart manufacturing" is the product of AI's complicated algorithms making use of information gathered from cyber-physical systems (Jan Z., Ahamed F., Mayer W., Patel N., Grossmann G., Stumptner M., Kuusk A., 2023). We now have the opportunity to meet the "digital representation" of a genuine existent physical component of equipment or a whole system, also known as a "digital twin," as the digital world quickly expands to satisfy the demanding demands of the industrial business. Because the AI models employed in digital twins lead to better monitoring and distribution of energy resources and also give projections for sufficient preparation, they provide the sector with the possibility of performing energy management with greater efficiency. Additional evaluation and repetition may be done in this virtual environment, leading to optimal performance and the development of clever methods based on targets for lowering carbon emissions. The AI tool makes use of machine learning by looking at past data in the form of maintenance logs. When a machine learning system has been trained on previous data, it may use real-time sensor inputs to accurately forecast when maintenance is needed. Most exciting is that there will be no additional charges for the heightened surveillance (TechInformed, AI leads the road to Net Zero, 2022, https://techinformed.com/).

Optimal maintenance workflows for industrial processes may be developed using a combination of predictive maintenance and other AI-based technologies, such as time for maintenance prediction and maintenance job scheduling. The ability to manage the use of replacement components is crucial to reducing emissions. A large amount of carbon might be saved if maintenance was performed only when necessary. This would reduce demand for both power and human labor, as well as the direct production of greenhouse gases. As stated by the World Economic Forum (https://www3.weforum.org/), "companies need to understand their current level of maturity in capturing value from data and analytics both within the company and across data ecosystems in order to drive value creation." (2021) World Economic Forum, Data Excellence: Transforming Manufacturing and Supply Systems.

The community behind the Unlocking Value in Manufacturing via Data Sharing effort collaborated to create the structure displayed in Figure 7 (Manufacturing Data Excellence structure). The framework is made up of three primary pillars (application areas, organizational enablers, and technology enablers) and enables businesses to evaluate their level of progress along about 20 parameters in terms of deploying value-adding applications and enablers. This prompts companies to assess their current state, identify areas for improvement, and plot a course of action to fully mature. More advanced analytical and data collection applications may be implemented, and data ecosystems can be constructed, as maturity levels rise. This aids in making plans for moving ahead, such as the implementation of a strategy for change or the introduction of new projects. By establishing a shared goal of data excellence and fostering the development of new collaborations to address shared challenges, the framework ultimately facilitates cross-organizational cooperation.

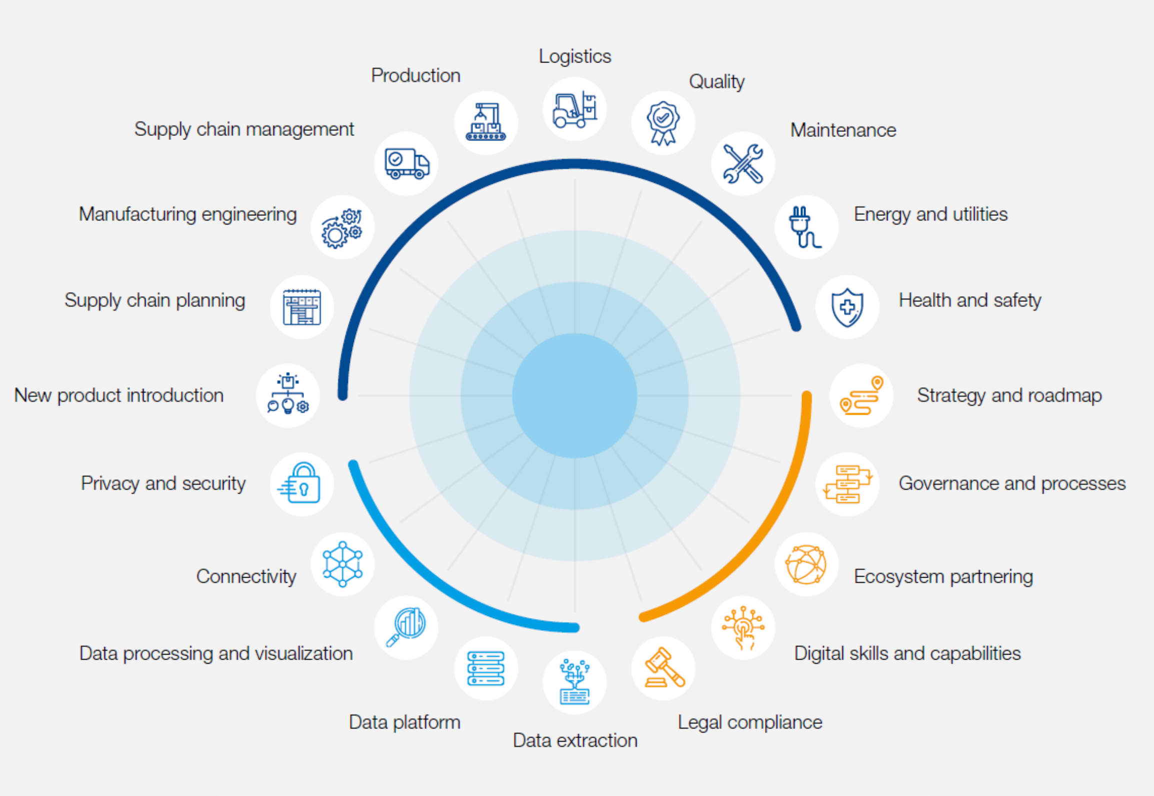


Figure 7. Manufacturing Data Excellence Framework (The World Economic Forum,2022).

To link and share information with other systems and devices through the Internet or additional communication networks, physical items with sensors, processing capabilities, software, and other technologies are referred to as "Internet of things" (https://en.wikipedia.org/). Product designers, for instance, may benefit from open access to a global implementation of IoT by using the knowledge gleaned through IoT to generate value out of other people's trash. Manufacturing processes are about to be linked such that neutral extracted materials are used, zero waste dispose of, and net-zero emissions are produced. Until now, the entire globe has established manufacturing processes individually, rather than integrated value chains across sectors. The sooner industries adopt the IoT technologies, the better the results will be in terms of circular economy and net zero emissions (TechInformed, Artificial Intelligence drives the way to Net Zero,2022, https://techinformed.com/). Both materials and energy consumption can be shared to reduce CO2 emissions drastically.

Several Internet of Things (IoT) applications may help businesses of any kind lessen their impact on the environment. Up to half of retail businesses across the world have used some kind of Internet of Things (IoT) technology already. Eighty percent or more of these pioneers claim to have seen dramatic improvements in energy and operational savings, leading to higher profits. Using some of the following recommendations, many other businesses are using the IoT's capacity to fight climate change and lessen their carbon impact.

a) IoT in order to to Increase Energy Efficiency

Businesses that have used IoT systems claim lower carbon emissions and greater energy efficiency. General Electric's Digital Power Plant is a good illustration of the synergy that can be achieved when hardware and software are designed with the Industrial Internet in mind. This plant is able to reduce energy consumption by as much as 62.2% simply by meeting the varying demands placed on power assets. Asset Performance Management (APM) solutions from GE have the power to foresee and prevent operational issues, cut downtime, and increase overall asset performance and life due to their ability to rapidly analyze data spanning years, systems, and equipment types (Asset Performance Management (APM) Software, GE, https://www.ge.com/). This is possible as a result of sophisticated analytics and domain knowledge being combined to convert reactive and preventive maintenance into predictive operations, turning raw data into actionable insight. By doing so, a plant is managed with the overarching objective of operations optimization, whereby superior visibility, insight, and suggested action are provided at all levels to achieve daily and over time operational excellence in conformity with standard norms. Although these developments are being launched in the energy sector, the same technologies have application in other sectors as well.

b) IoT in order to Improve Lighting Efficiency

Companies often look for ways to increase the efficiency of their lighting since it is one area that uses a lot of power. The "Energy Star" label has been accepted as a standard by several manufacturers to guarantee their dedication to energy efficiency in their products. Internet of Things (IoT)-enabled smart lighting sensors, however, make lighting smarter and more responsive by turning on and off automatically in response to the presence or absence of people and by adjusting the brightness of the lights in response to the amount of natural light present, the time of day, or other external factors (THE MEDIA, 2022, https://renlor465.amebaownd.com/).

c) IoT in order to Improve Heating and Cooling Efficiency

In order to lessen their impact on the environment, many businesses depend on energy-saving heating and cooling systems. Maintaining air filters, ventilation ducts, and other Heating-Ventilation-Air Conditioning (HVAC) equipment is one way for businesses to reduce the amount of energy used by their HVAC systems (United States Environmental Protection Agency, 2022, https://www.epa.gov/). Effective maintenance is already the norm in many sectors because to laws and regulations mandating it. Smart heating and cooling systems, intelligent plugs, and other Internet of Things (IoT) devices may significantly cut energy usage and associated carbon emissions. All of the aforementioned have a wide range of domestic and business uses, but they may also be used in a number of industrial contexts.

d) IoT in order to Switch to a Paperless Environment

Moving to a paperless environment, made possible via the usage of IoT devices, is crucial to reducing one's carbon footprint. The vast majority of businesses acknowledge that they use and dispose of enormous quantities of paper for things like labels, receipts, promotional materials, and routine paperwork. Constantly using paper products has obvious environmental consequences, but there are several Internet of Things (IoT) devices that may be utilized as energy-efficient replacements for paper, like Electronic Shelf Labels (ESLs). Industries are making use of this development by switching from paper labels to interactive LED displays for containers, goods, and storage facilities. Smart product displays with interactive buttons for sales and marketing promotion are a hallmark of these systems (Solum, 2022; https://www.solumesl.com/).

e)IoT in order to Optimize and Automate Supply Chain

The Internet of Things is an essential component of a fully automated supply chain management system. When implemented in warehouses and shops, devices built to IoT standards provide the advantage of real-time inventory management, as well as an additional chance to measure sales, coordinate purchasing needs, and optimize store layouts.

f) IoT Solutions in order to Solve Oil and Gas Refinery Challenges

Competition, increased complexity, and more stringent rules are just a few of the formidable obstacles that the oil and gas business must overcome. These variables, along with decreasing predictability, cause profit margins to shrink despite continuing efforts to maximize efficiency in operations and asset performance.

Tools and techniques that efficiently and promptly handle operational risks including leakage, maintenance of equipment, malfunction, and volume production are one solution to these problems. Managing leaks in particular is crucial because they may cause explosions, fires, and environmental damage; these issues also have significant monetary worth.

Both inadvertent (leaks or runaway emissions) and purposeful (venting) greenhouse gas emissions come from the petroleum industry. Equipment that is either poorly maintained or run inefficiently emits much more greenhouse gases. Cloud computing and the development of remote sensors designed for use in dangerous settings have made it possible to remotely monitor a facility's operations, including the release of fugitive gases. United States Environmental Protection Agency, GREENHOUSE GAS EMISSIONS REPORTING FROM THE PETROLEUM AND NATURAL GAS INDUSTRY, https://www.epa.gov/). They may increase operational efficiency and profitability by increasing asset visibility and safety in refineries.

Low-maintenance Internet of Things (IoT) solutions like this enable customers to set up an invisible emissions monitoring system rapidly and at a reasonable cost. To monitor processes and aid the analytics algorithm in spotting abnormalities before they become serious, these gadgets were designed specifically for the industrial sector. Data from sensors uploaded to the cloud paves the way for preventative maintenance and immediate notification of any outliers in the collected data.

CHAPTER 4: TYPICAL CARBON FOOTPRINT IN REFINING

4.1 Introduction

The oil refining business, which began in the middle of the 19th century, is now fundamental to contemporary life. However, there is evidence that indicates that the worldwide increase of greenhouse gas emissions and local airborne pollutants due to the combustion of fossil fuels have resulted from the enhancing of crude oil to generate transportation fuels, petrochemical feedstocks, and a variety of other products. Therefore, the oil refining industry faces an immediate need to decarbonize its operations and provide support for the decarbonization of the end use sectors that it directly affects (Griffiths S., Sovacooj B., Kim M., Bazilian M., Uratani M., "Decarbonizing the oil refining industry: A systematic review of sociotechnical systems, technological innovations, and policy options," Energy Research & Social Science 2022).

The worldwide refining industry, which supplies transportation fuels and chemicals, expanded its production capacity by 13% between 2000 and 2018, resulting in a 24% rise in overall GHG emissions (Lei et al., 2021). While consumption of refined petroleum products has been on the decline in Europe and Latin America, it has seen substantial growth in India and China due to the rapid industrialization of these countries and the rising demand for transportation services (Frontiers in Chemical Engineering, 2022, https://www.frontiersin.org/). In fact, over 150 more refineries are expected to be operational throughout the Middle East, Africa, and Asia by 2025 (Lei et al., 2021). This might create a barrier and provide an inherent obstacle to achieving carbon-neutrality targets. It is required to give some statistical data related with the refining industry in order to introduce and emphasize the amount of its contribution to carbon footprint.

To begin, oil refineries continue to be a significant contributor to global greenhouse gas emissions, accounting for around 5% of all such emissions during the previous decade, third only to power facilities and natural gas networks. The United States Environmental Protection Agency (EPA), PETROLEUM REFINERIES SECTOR, 2013, https://www.epa.gov/, ranks the petroleum refining industry as the second most polluting industry in the country per facility, behind only the electric power generation industry. About two-thirds of the greenhouse gas emissions in the refining industry come from stationary fuel burning. As a result, oil refining is an essential part of the energy infrastructure and the global warming debate. About 98% of the emissions from petroleum refineries are composed of carbon dioxide.

4.2 Categories of Emissions in Oil Refinery Industry

Topping refineries, hydroskimming refineries, cracking refineries, and coking refineries are the four most frequent kinds of refineries. The refineries of these sorts are able to handle larger grades of crude oil due to their more complicated layouts. Facilities in the oil refineries industry generate finished petroleum products including gasoline, naphtha, kerosene, distillation fuel oils, leftover fuel oils, lubricants, and asphalt via various processes like distillation, re-distillation, cracking, and reforming. The United States Environmental Protection Agency (EPA), GHGRP Refineries (2022), https://www.epa.gov/, reports that greenhouse gas emissions result from petroleum refining operations, venting, flaring, and fugitive leaks from equipment including valves and pumps.

Emissions from other types of stationary combustion units are also included here, with the exception of power plants. Most oil refineries also list themselves as providers of petroleum products, and some even list themselves as carbon dioxide suppliers. Static fuel combustion units (such as boilers for steam, process combustion appliances, and process heaters) are the primary contributors to greenhouse gas emissions in petroleum refineries. Catalytic cracking units, fluid coking units, catalytic reforming units, coke calcining units,delayed coking units, asphalt blowing operations, machinery leaks,blowdown systems, storage tanks, , flares, loading operations as well as sulfur recovery plants are all reported as sources of emissions in the petroleum refineries industry. According to the United States Environmental Protection Agency, the total estimated emissions from these activities and fuel burning in 2013 are shown in Figure 8. CO2 accounts for approximately 98 percent of all emissions in petroleum refineries, as shown in Figure 9 of which greenhouse gases are released by refineries in the United States.

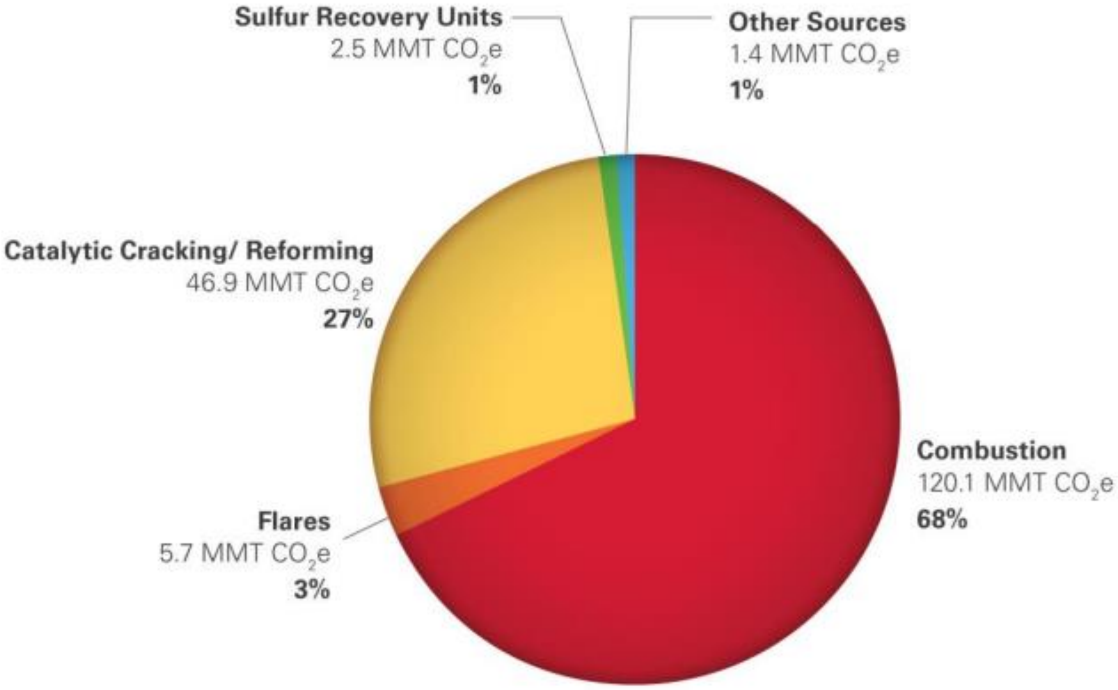


Figure 8. Petroleum Refineries Sector in U.S. - Emissions by Source (Environmental Protection Agency U.S., 2013).

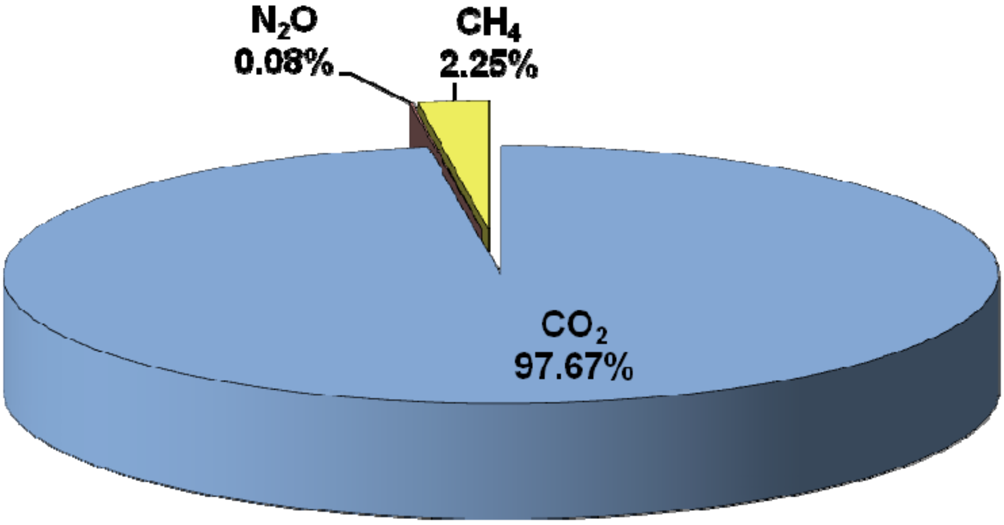


Figure **9**. Greenhouse gas emissions from petroleum refineries in U.S. (Environmental Protection Agency U.S., 2013).

4.3 Process units and emissions sources at petroleum refinery

Petroleum refining is a multi-step process that transforms crude oil into useful byproducts including gasoline, diesel, jet fuel, fluids, heating oil,and chemicals. Figure 10 (Teledyne Monitor Labs, Petroleum Refining, https://www.teledyne-ml.com/) shows the primary process units found in a refinery, and this figure will be used as a reference for the following discussion.

4.3.1 Stationary Combustion Sources

At a petroleum refinery, the majority of emissions from combustion sources that are not mobile are greenhouse gases. However, combustion sources can release trace quantities of methane (CH4) and nitrous oxide (N2O). Combustion turbines, boilers, and various other similar equipment, as well as process heaters utilized throughout the whole refining process, are all examples of such energy generators. Crude oil atmospheric and vacuum distilling units, as well as the catalytic reforming unit, are often linked with the biggest process heaters in a petroleum refinery. Many operations in a refinery need not just direct process heat but also steam and electricity. Some refineries buy steam to satisfy these needs. Some businesses get all the steam they need from specialized on-site boilers. Refineries without cracking equipment may have the majority of greenhouse gas emissions come from a boiler used to generate steam for the operation.

RFG, or still gas as it is more often known, is the primary fuel source for oil refineries. RFG is a gaseous byproduct of distillation that includes light hydrocarbons (C1–C4), hydrogen sulfide (H2S), hydrogen, and other gases that do not condense in the overhead condenser. The fuel gas system is responsible for the collection and distribution of RFG. Depending on the layout of the refinery, the fuel for the various process heaters & boilers may come from a number of separate fuel gas systems. In order to meet the refinery's total energy demands, natural gas is often added to the fuel gas produced on site. The quantity of supplementary natural gas required might vary widely depending on the crude oil being refined and the number of active process units. United States Environmental Protection Agency. (2016). Direct Emissions from Stationary Combustion Sources. https://www.epa.gov/. As a result, fuel gas composition may vary significantly between refineries and even within a refinery as units are taken offline for maintenance.

4.3.2 Flares

During process upsets, equipment breakdowns, and unit start-ups and shutdowns, flares are utilized to safely receive gases in refineries. In order to keep the flare ready in the case of a major failure or process upset, some flares only receive minimal volumes of "purge" or "sweep" gas to avoid oxygen from reaching the flare header and, perhaps, the fuel gas system. Some flares may be employed purely as controls for regulatory reasons, while others may be utilized on a regular basis to dispose of surplus process gas. When gas is burned in a flare, a variety of pollutants are produced, most notably carbon dioxide but also some methane and nitrous oxide (US EPA, Chapter 1 Flares, 2019, https://www.epa.gov/).

4.3.3 Catalytic Cracking Units

Catalytic cracking is a method of reducing the size of big hydrocarbon molecules by using heat and pressure in conjunction with a catalyst. According to the United States Environmental Protection Agency's Available and New Technologies for Reducing Greenhouse Gas Emissions of the Petroleum Refining Industry (2010) (https://www.epa.gov/), the fluid catalytic cracking unit (FCCU) is the most widely used unit of its kind.

The regenerator section's tiny catalyst particles are heated to about 1,300 degrees Fahrenheit (oF) in the feed line, where they come into contact with the FCCU feed after being preheated to temperatures between 500 and 800 oF. After coming into contact with the heated catalyst, the feed vapor, which is crude or vacuum distillation column heavy distillate oil, undergoes a chemical reaction that cracks the big hydrocarbon molecules into a number of lighter hydrocarbons.

Coke is deposited on the catalyst's particles during the cracking process, rendering them ineffective. After the reacted vapors have been transported to a fractionation tower, the catalyst is recovered from the reactor and sent back through the FCCU's regenerator to have its coke deposits burned away. Coke accumulated on catalyst particles during cracking is burned in the FCCU catalyst regenerator, releasing greenhouse gases. During "coke burn-off," CO2 is again the predominant emission, followed by trace amounts of CH4 and N2O. The degree of combustion is adjustable in an FCCU catalyst regenerator. To avoid producing harmful levels of carbon monoxide (CO), a complete-combustion FCCU requires enough of oxygen during operation. Since partial-combustion FCCUs produce both CO and CO2, a CO boiler is usually installed after them to transform the CO to CO2. During catalyst regeneration, most refineries that utilize an FCCU recover useable heat by burning catalyst coke, which helps to meet the refinery's supplementary energy demands. When it comes to emissions produced by a refinery, the catalyst regenerating or coal burn-off venting is often the greatest single source.

In contrast to fluid catalytic cracking units (FCCU), thermal catalytic cracking units (TCCU) employ a moving bed reactor with larger catalyst particles. However, GHG emissions continue to be produced in the TCCU's regenerator when coke accumulated on the particles of catalyst is burnt off to restore catalytic activity.

4.3.4 Coking units

Coking is another kind of cracking process used in refineries to convert lower-value fuel oils into higher-value transportation fuels like gasoline and diesel. Petroleum coke is a valuable byproduct of the coking reaction because it can be burned to generate electricity or used as a raw material in the production of carbon and graphite (U.S. Environmental Protection Agency, Technical Support Document for the Petroleum Refining Sector: Proposed Rule for Mandatory Reporting of Greenhouse Gases, 2008, https://www.epa.gov/).

To improve their capacity for processing heavier crude oils, refineries will typically add coking units. Coking units may be divided into three categories: those that use a delayed coking process, those that use fluid coking, and those that use a flexi-coking process. The majority of coking units are delayed cokers, and this trend is projected to continue for the foreseeable future.

4.3.5 Catalytic Reforming Units

To create aromatic chemicals like benzene, the CRU reacts low-octane hydrocarbon distillates like gasoline and naphtha with a catalyst. The reforming process produces hydrogen, which is a useful byproduct. Catalytic hydrotreaters are often used to treat the feed to the CRU for nitrogen, sulfur as well as metallic impurities. A typical CRU will include between three and four interconnected reactors. The feed must be heated before each reactor vessel since the reforming reactor is endothermic. United States Environmental Protection Agency, Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Petroleum Refining Industry, 2010, https://www.epa.gov/), coke deposits slowly on the catalyst particles during the processing reaction, and this "catalyst coke" must be burned-off to reactivate the catalyst. This results in CO_2, along with small amounts of CH_4 and N_2O.

4.3.6 Sulfur Recovery Vents

Amine scrubbers are used to remove hydrogen sulfide (H_2S) from the fuel gas system in a refinery. These scrubbers tend to remove CO_2 off the fuel gas, whereas the effectiveness of H_2S removal is based on the kind of amine solution utilized. In a sulfur recovery facility, the H_2S is refined into pure sulfur or sulfuric acid once the sour gas has been condensed. The sulfur recovery facility will allow the CO_2 in the soured gas to escape via the final vent. Slight quantities of hydrocarbons can additionally coexist with the sour gas. The sulfur recovery facility or the tail gas incinerator will finally convert these hydrocarbons to carbon dioxide.

4.3.7 Asphalt Blowing Stills

When making asphalt roofing goods or some types of road 10 asphalt, asphalt and bituminous blowing is used to polymerize and stabilize the asphalt, hence improving its weathering qualities. In asphalt blowing, liquid asphalt flux is oxidized by blowing air through it at 260 °C (500 °F) for anywhere from one hour to ten hours to get the necessary properties. Asphalt blowing is performed in a special vessel known as a "blowing still." Organic particle matter, including both hydrocarbon and polycyclic substances, and reduced sulfur compounds are the most abundant of the emissions from a blown still. Wet scrubbers remove sour gas, entrained oil, particulates, and condensable organics, while thermal oxidizers convert hydrocarbons as well as sour gas to SO2 and CO2 (United States Environmental Protection Agency, Locating & Estimating Air Emissions from Sources of Polycyclic Organic Matter, https://www.epa.gov/). The blowing still gas also contains significant quantities of CH4 and CO2.

4.3.8 Storage Tanks

Greenhouse gas emissions from storage tanks are typically low, but may increase when unstabilized crude oil is kept if a methane blanket is utilized. According to the United States Environmental Protection Agency's Control of Vapor Losses from Production Tanks (2010) (https://www.epa.gov/), un-stabilized crude oil is crude oil which has not been held at atmospheric conditions for extended periods of time prior to being received at the refinery. Natural gas, such as CH4, dissolves in the crude oil due to the high pressure present in the crude oil deposits. To either release or reclaim the dissolved gases, crude oil is frequently briefly kept at atmospheric conditions after extraction. If the crude oil is shipped under pressure both immediately or soon after the extraction process, the gases that are dissolved will stay in the crude oil till it reaches the refinery, and will be released from the "un-stabilized" crude oil when it remains at atmospheric conditions in a tank of storage at the refinery.

4.3.9 Coke Calcining Units

Some petroleum refineries have onsite coke calcining machines, despite the fact that these equipment are a major contributor to CO2 emissions. Electrodes, anode containers, and other items may all benefit from premium quality coke, which is produced in coke calciners by burning out sulfur, volatile substances, and other impurities. Because only a tiny amount of the coke is actually used, the process gas created must be burned in an afterburner, which involves combining the gas with air and a flame. This afterburner process accounts for the vast majority of the CO2 emissions.

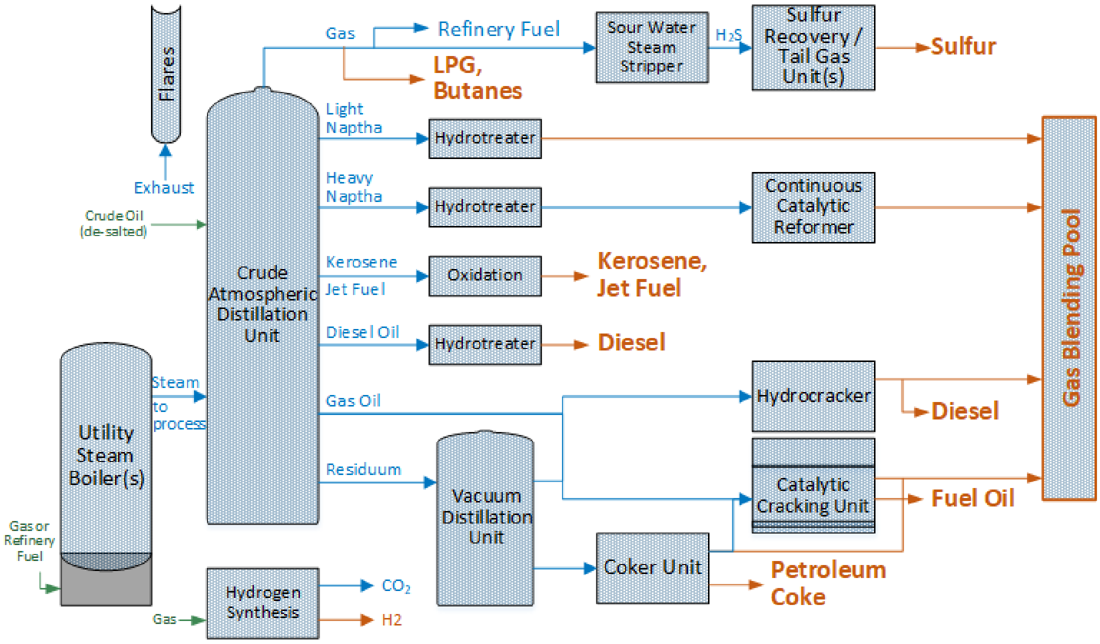


Figure 7. Petroleum Refining (Teledyne Monitor Labs).

4.4 Techniques for neutral carbon emissions

The process systems engineering industry has made strides in addressing a number of emission reduction issues by developing process integration strategies. Methods of merging activities inside a process or across processes to cut down on resource consumption and/or hazardous emissions are closely connected to process integration methods (Klemes, 2013).

Methodologies for integrating processes may be broken down into two broad categories: those centered around pinch analysis and those relying on mathematical optimization approaches (Foo D., Tan R., 2016).

A. Decomposition algorithm for segregated targeting. A pinch analysis.

Bandyopadhyay et al. (2010) (Figure 11) suggested a decomposition technique with high efficiency levels to solve the challenge of locating carbon-neutral energy sources. The aforementioned approach is general in nature, allowing it to be used to the determination of the minimum need of net CO2-neutral and low-carbon energy sources across all areas by any targeting technique based on the similar source-demand model. The technique is applicable to a wide range of environmental challenges, including those involving carbon emission factors, energy transformities, etc. (Foo D., Tan R., 2016). The segregated targeting issue is about minimizing the amount of an external resource used by a process network that has many zones, each with its own unique set of needs. However, there is a shared set of internal resources amongst all the different zones. By breaking the issue down into smaller, more manageable chunks, the decomposition algorithm makes it possible to control the lowest amount of each resource needed by using different targeting techniques (Jain S., Bandyopadhyay S., 2021).

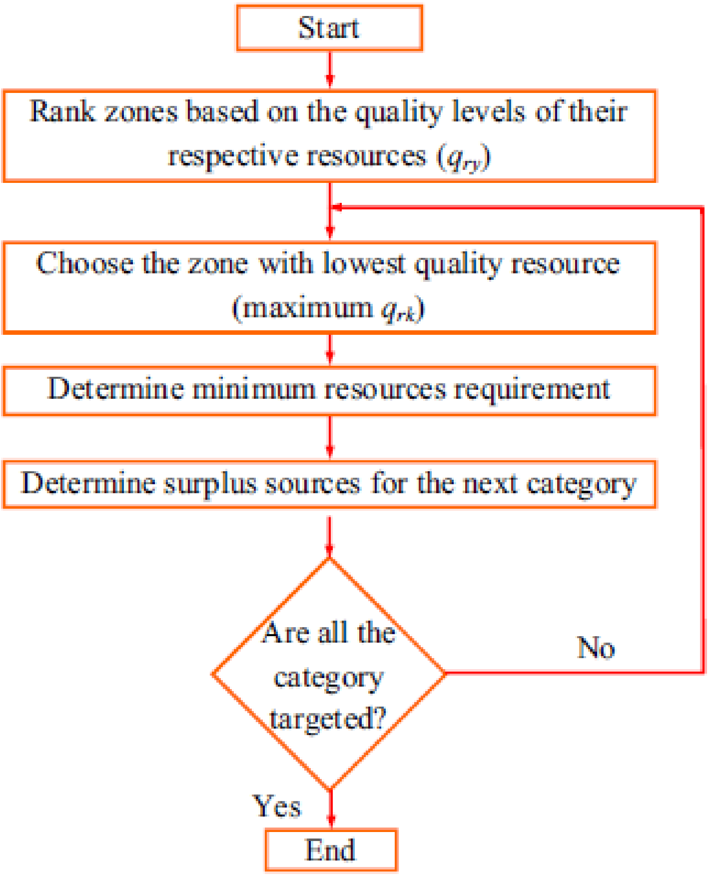


Figure 11. Flow chart of decomposition algorithm for segregated targeting (Bandyopadhyay et al., 2010).

B. Sustainable power generation with CCS-mathematical optimization technique.

Greenhouse gas emissions from the production of electricity are significant. Some of the world's biggest greenhouse gas emitters, such as the United States and China, continue to rely on fossil fuels, particularly coal, for the provision of their electricity despite the rising popularity of low-carbon energy production technologies like wind, hydroelectric, and nuclear.

Carbon capture and storage (also known as "CCS") is gaining popularity because it makes it possible to burn fossil fuels while reducing their carbon emissions. Carbon collection and CO2 storage are key to this process.Carbon capture is the process of removing CO2 from other major point sources so that it may be safely disposed of in a location other than the atmosphere. Theoretical approaches like "chemical looping combustion," which relates to combustion or partial burning using a carrier of oxygen for transferring oxygen from the air to fuels, are being researched as well alongside more practical methods like chimney gas scrubbing, oxy-fuel ignition, and fuel gasification. After CO2 is separated from the rest of the atmosphere, it may be stored in a number of "sinks," including salty aquifers, exhausted oil fields, and unreachable coal beds (Davison et al., 2001). The approach does have the desirable effect of lowering emissions. In contrast, plant production and thermal efficiency suffer when CCS is used due to parasitic power losses caused by the energy-intensive nature of carbon capture systems. Power production is expensive due to power loss and the requirement for new, expensive equipment (Wall, 2007; Yang et al., 2008). Since new plants must be constructed to make up for the drop in power generation, higher emissions are another major drawback of CCS implications. The latter might be seen as a never-ending loop, or the difficulty of finding a happy medium between economic and environmental issues when determining the optimal degree of CCS deployment. Figure 12 from (Foo D., Tan R., 2016) shows an illustration for the CCS issue.

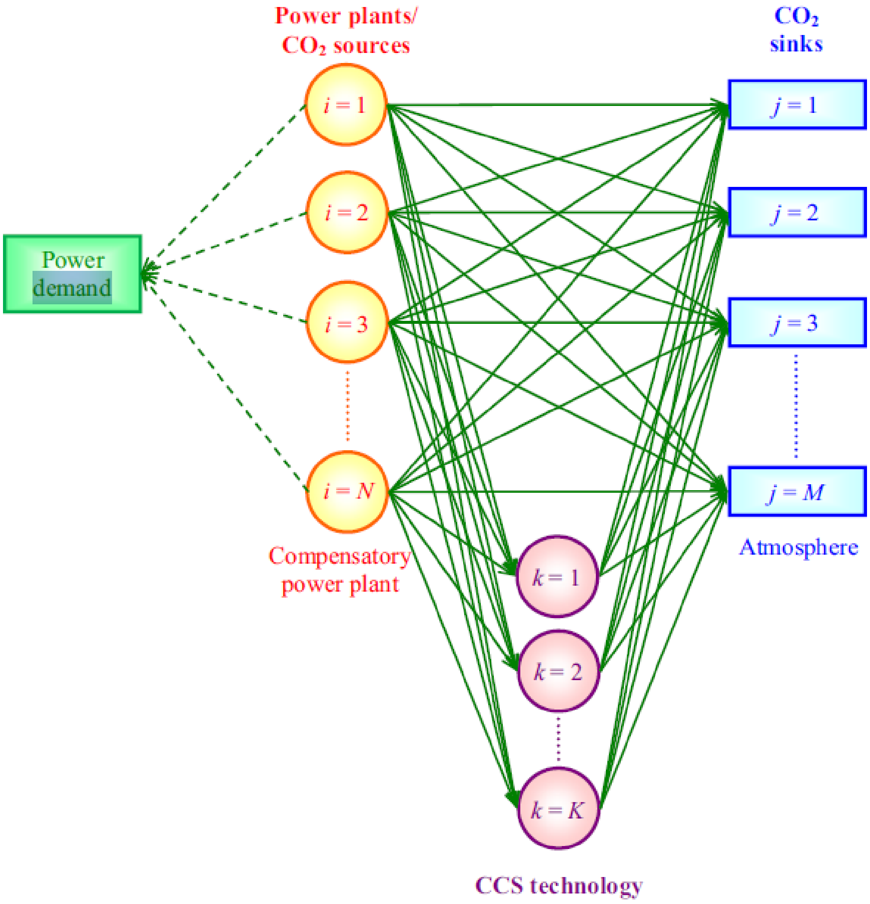


Figure 12. Source-sink superstructure for sustainable power generation with CCS (solid lines indicate CO_2 allocation; dashed lines indicate power transmission; adapted from Pekala et al. (2010) and Lee et al. (2014).

4.5 A multipronged approach for net zero effects

The goal of the net-zero effort is to remove as much carbon dioxide from the air as is being released into the environment. The development of the CCS process, which has resulted in CO2 collection rates exceeding 90%, has received more attention than it otherwise would have gotten due to the enormous uncertainties surrounding the eventual cost of technologies utilized to fulfill the aforementioned purpose. Even if post-combustion CCS can attain very high capture rates, it may not be enough to completely remove emissions from a refinery.

Because of the unpredictability of unexpected flaring (equipment breakdowns, blow downturns, or emergency shutdowns), it is also recommended to use a multifaceted strategy rather than rely just on post-combustion CCS for handling flared gases. Post-combustion carbon capture and storage (CCS) combined with fuel switching is the best solution for achieving net-zero emissions in oil refineries (2022, Frontiers in Chemical Engineering, A Pathway Towards Net-Zero Emissions in Oil Refineries, https://www.frontiersin.org/). They are able to reduce emissions from refineries in a cost-effective manner because the first component targets the main point sources of emissions while the second component targets lesser scattered emissions. When there is a shortage of room for the CCS implementation and other on-site ancillary equipment, fuel switching is an acceptable alternative. More research is required, however, to illuminate and clarify the differences between post-combustion CCS as well as fuel shifting taking into account economic and environmental implications as well as the maturity of the relevant technologies.

CO2 avoidance is the amount of CO2 emissions that are prevented using mitigation strategies, as compared to what would be emitted by a plant utilizing the same fuels and technology. An avoidance assessment must include both "Scope 1" and "Scope 2" emissions if strategic choices are to be completely aligned with net-zero aspirations. Increasing the CCS plant's rate of CO2 collection sets off a chain reaction that raises total energy consumption and has subsequent indirect environmental implications. In a similar vein, indirect greenhouse gas emissions associated with the upstream processes needed to produce hydrogen, electricity, or biofuels significantly reduce the total benefit of fuel switching.

4.6. Decarbonization and Energy Efficiency Roadmap in Oil Refining Sector

Effectively anticipating the effects of potential future changes on markets, technology, and goods is the goal of road mapping. It makes use of both in-house and outside resources. As has been indicated before in this article, the oil refining industry is under pressure to restructure due to several factors connected to sustainability. Oil refineries must use decarbonization technologies such as advanced biofuels, green hydrogen, and CCS (carbon capture and storage) to facilitate the shift to a low-carbon economy. Decarbonizing the refinery sector: a socio-technical assessment of advanced biofuels, green hydrogen, and carbon storage and capture developments in Sweden, 2022, https://www.researchgate.net/). However, developing and implementing such technologies is not a simple task and their dependency is under question. The Department of Climate Change and Energy and the Department of Business, Innovation, and Skills have collaborated to develop a plan that takes use of current prospects for decarbonization and energy efficiency improvement without sacrificing competitiveness. Department of Energy and Climate Change and Department of Business, Innovation and Skills, Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050, 2015, https://assets.publishing.service.gov.uk/). The oil refining road map development is carried out in three parts.

A) Data Collection - Data analysis of publicly available sources, a review of relevant literature, and in-person interviews with subject-matter experts all contribute to a complete picture of the factors driving or slowing down investment in decarbonization and energy efficiency technologies. There is "overlap" between the "barriers and enablers" of decarbonization in the oil refining industry, which suggests that certain issues are seen from two distinct angles.

Government policies that incentivize decarbonization investment are a key enabler.

- Adherence to rules and regulations.
- Significant cooperation between business, government, professional groups, and educational institutions.
- Recognition by the government of the oil refining industry's strategic significance.
- Incorporating concerns about climate change and the need to develop long-term energy strategy into company goals.

What we mean by "cost savings" due to "energy savings" Despite its apparent benefits, rising energy prices are a real concern.

The list of obstructions includes the following items:

- Adherence to rules and regulations.

Market circumstances were unfavorable due to many factors, including: demand harm, negative cash flow, and uncertainty.

- The management team's lack of interest in decarbonization is attributable to the organization's concentration on the short term.
- Vehement rivalry is impeding efforts to work together on decarbonization initiatives.
- Exorbitant and rising prices for energy.
- A lack of vital skilled workers and a corresponding delay in the "return on investment" for applied sophisticated technology.

B) Development of decarbonization “pathway”

Pathways are being developed with the goal of locating and studying a broad variety of technologies that may help bring down emissions of various greenhouse gases. To accomplish reductions in carbon emissions within a certain range compared to a reference pattern in which no choices are deployed, a route specifies a precise selection and implementation of options over a defined time period.

There are two further defined routes that evaluate (i) the status quo if no extra interventions were made to speed up carbon reduction (business as usual) and (ii) the sector's theoretically feasible maximal technological capability for decarbonization (Max Tech).

Deployment of options such as (i) small enhancements on current technology, (ii) improvements to utilize the most effective technology at hand, and (iii) the application of major procedure changes using "disruptive" technologies that have an opportunity to become economically feasible in the medium term are all examples of possible routes.

As an example of the "Roadmap report" for the UK market, Figure 13 depicts this kind of study.

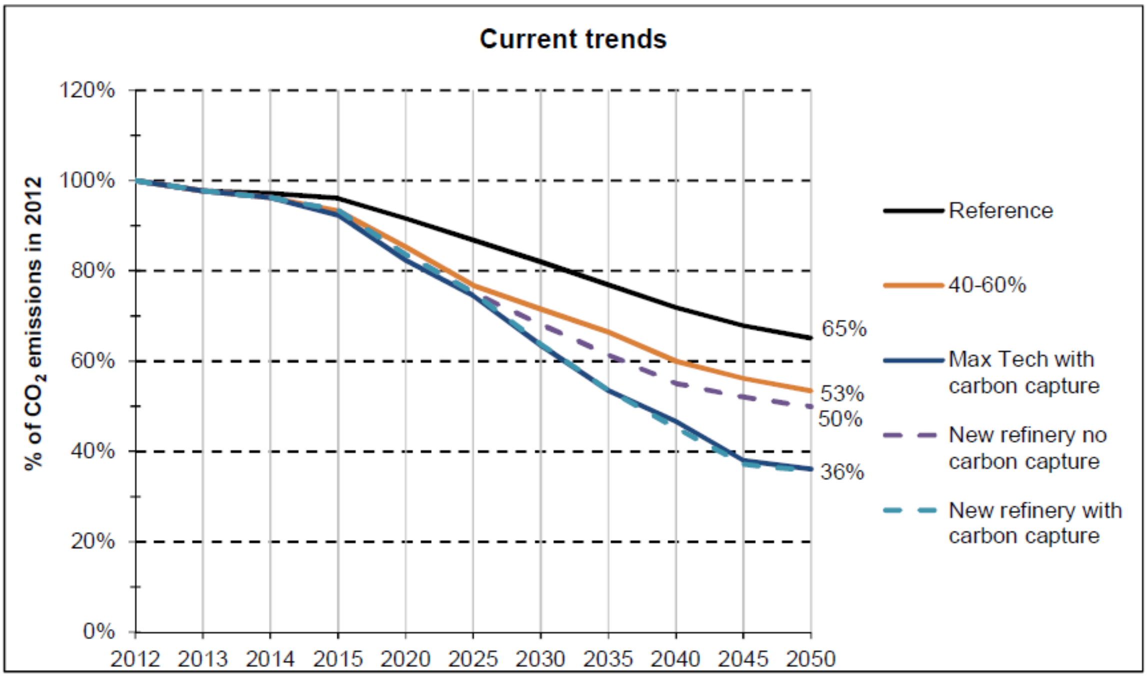


Figure 8. Pathways to decarbonization of the oil refining sector, current trends scenario (Department of Energy and Climate Change and Department for Business, Innovation and Skills, 2015).

The capital costs associated with each potential outcome of this scenario are calculated and tallied here. For solutions that are yet to reach the development stage, this analysis creates a great deal of ambiguity. Furthermore, the preceding analysis does not account for other factors that impact the capital cost. Included in this category are operational, energy, R&D, demonstration, civil works, plant modification, and other expenditures. A part of the expenses associated with substantial capex items installed near to 2050 are not included since they belong to the study timeframe and are modified to eliminate any remaining worth after the end of it. The method in which these expenses are understood is another factor to consider while attempting to resolve the problem. Stakeholders in the sector need to take into account the magnitude of the investments associated with the pathways (Department of Energy and Climate Change and the Department of Business, Innovation and Skills, Industrial Decarbonization & Energy Efficiency Roadmaps to 2050, 2015, https://assets.publishing.service.gov.uk/) even though implementing some of the options within the routes may reduce energy costs due to increased efficiency.

C) Conclusion drawing –

Once the data has been acquired and evaluated, the following stage is to interpret and analyze the technical, social, and business information to identify the best course of action. These measures are intended to help overcome phase one hurdles using specific technology from the decarbonization routes.

The last thoughts on several subjects, such as:

- Planning, Management, and Structure

All parties involved—the government, the refining industry, and everyone else who has a stake in the sector’s future—must acknowledge the strategic and long-term significance of the industry in terms of decarbonization, energy efficiency, and overall competitiveness.

Challenges to the Business Case

Due to external competition, many companies lack the initial money necessary to invest in research and development and the commercial implementation of important innovations. It is difficult for enterprises to compete for scarce investment capital due to the industry's protracted investment cycles and the perception of high operational expenses. Low profit margins make oil refining an unattractive investment. Most of the time, the conditions of external financing do not conform to internal investment standards.

Costs, Market Structure, and Competition in the Energy Market in the Future

As was noted, market rivalry is fierce, limiting opportunities for effective energy efficiency cooperation. Refiners do not have best practices because they see energy efficiency measures as a competitive advantage.

Individuals and Abilities

Staff resources with expertise in heat and energy engineering are urgently needed in the sector. Currently, energy teams' primary duties involve assuring compliance with current laws, which takes time and resources away from identifying and implementing opportunities to improve energy efficiency.

Availability of Fuel and Raw Materials

Although biomass has a small impact on lowering emissions from the oil refining industry by offsetting the use of natural gas, the availability of carbon-neutral fuels is a major issue for the decarbonization of this sector. This accessibility problem might be addressed either from inside the industry, via the adoption of biomass as a source of fuel, or from outside, through the utilization of other resources, such as waste plastics for power production. Locating the areas with the highest decarbonization potential while also making the most of the available resource is a significant problem. • Energy Efficiency and Heat Recovery

These methods are largely accepted, provide little technical risk, and may reduce emissions and operating costs. However, better availability of financial and human capital is necessary to properly use this alternative.

Carbon Sequestration

While refineries may be of a size to warrant their own CO2 pipeline and infrastructure for storage, building such networks through collaboration with third-party sectors improves both network establishment and access to funding sources that are suitable for such shared infrastructure.

- Future Actions

In order to facilitate the implementation of future policies and the delivery of subsequent activities, the purpose of the roadmap analysis is to give such an evidence-based basis. The government recognizes it as a valuable addition to its future strategies and initiatives (Department of Energy and Climate Change and the Department for Business, Innovation and Skills, Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050, 2015, https://assets.publishing.service.gov.uk/), and it satisfies the condition to perform with credibility towards industrial, academic, and other stakeholders.

CHAPTER 5: METHODS FOR REDUCTION

5.1 Introduction

The oil refining sector faces significant obstacles on the road to decarbonization because the lifespan of refineries is extended, there are few incentives for implementing new technologies, and there is not much time to do so. When making a certain product, a single refinery may use a variety of processes, each of which has a unique carbon footprint. In addition, simpler refineries that can't handle the heavy percentages of their product transfer such compounds to the more advanced refineries for processing. Energy use and CO2 emissions are not easily correlated with straightforward metrics like crude throughput, end product mix, and so forth. Therefore, progress when it comes to of emissions is not reflected by a benchmarking strategy utilizing just these measures. Because of variations in end product mixtures and intermediate fraction treatment, the standardization method for refineries has to account for these variations in configuration. The integration and overlap with the petrochemical industry, as well as the varying degrees to which emissions from on-site electricity production, electricity imports and exports, and steam use present difficulties when comparing refineries (ECOFYS, Methodology for the free allocation of emission allowances in the EU ETS post 2012, 2009, https://climate.ec.europa.eu/).

Decarbonizing the oil refining industry: A systematic review of sociotechnical systems, technological innovations, and policy options" (Griffiths S., Sovacooj B., Kim M., Bazilian M., Uratani M.), Energy Research & Social Science, 2022) classifies the most common methods for lowering the industry's carbon footprint as follows:

Increased use of renewable energy sources, Carbon Capture Usage and Storage technologies, the use of low-carbon hydrogen, and improvements in energy efficiency, waste heat recovery, and the design effectiveness of operational units (in particular heaters and furnaces) are all examples.

After doing extensive research, ko Institute and Ecofys (2008) recommended two benchmarking approaches that do account for variations in refinery setups:

Solomon's "complexity weighted barrel" (CWB) approach, which was subsequently renamed "complexity weighted tonne" (CWT), and a "hybrid" approach. In Solomon's method, emissions per ton of crude oil are used as a standard, while in the hybrid system, emissions per ton of crude oil are distributed according to a predetermined scale (ECOFYS, Methodology for the free allocation of emission allowances in the EU ETS post 2012, 2009, https://climate.ec.europa.eu/).

- The CWT approach.

The CWT would be the only output of the refinery in this scenario. An emission factor, measured in terms of the CWT factor, is applied to each generic process unit in comparison with crude distillation. The factor for the crude distillation unit is set to 1, and the remaining factors represent the relative intensities of CO2 emissions from the other units operating at the same level of energy efficiency and using the same type of standard fuel for combustion across all process units.

Because refining is a holistic process, the total energy consumption is the typical factor used to establish the CWT factor of every procedure unit. CWT factors are exclusively used for internal weighing purposes between different units in a refinery. A refinery's performance may be measured against industry standards by comparing its actual emissions to its total CWT. CWT factors operate as weighting factors for various process units, thus adjusting one factor specifically affects the unit to which it refers. The 'output' of a refinery, measured in CWTs, is the sum of the outputs of its individual process units and, by extension, its level of "activity." Each process unit's CWTs are calculated by multiplying the CWT factor by the quantity of input it received within a certain time interval. An individual process unit's CWT factor in the refining industry is calculated by dividing its standard CO2 emissions per ton of throughput by the standard CO2 emissions per ton of oil throughput (ECOFYS, Methodology for the free allocation of emission allowances in the EU ETS post 2012, 2009, https://climate.ec.europa.eu/).

burning of fuels is the primary source of carbon dioxide (CO2) emissions from refinery processing units, although certain units can create "process" emissions from more targeted chemical processes, such as hydrogen synthesis, or from the burning of an internally generated fuel. In addition to words directly connected to process units, the algorithm of Solomon also predicts two additional terms as outliers.

A) the "off-sites" word, which refers to the common infrastructure, tankage, water treatment, and blending that operate inside the refinery's fence-line yet use energy.

B) the "non-crude sensible heat" phrase, which allows for additional provision to get the temperature of non-crude materials entering the refinery up to the temperature at which they would typically be accessible from, for instance, the crude distiller.

CWT is an operation function that captures the output and relative complexity of the plants without assuming anything about their emission performance. If two refineries attain a similar level of performance, their CWT scores may be equivalent, and their emissions may be same. In contrast, if both refineries produce the same CWT and one produces less pollutants, the former has performed better.

5.2 Decarbonization strategies

Griffiths S., Sovacooj B., Kim M., Bazilian M., Uratani M., "Decarbonizing the oil refining industry: A systematic review of sociotechnical systems, technological innovations, and policy options," Energy Research & Social Science 2022) list the following as examples of generally applicable decarbonization strategies:

- Equipment designed to recover waste heat as well as over-bottom pressure may do so from a variety of sources, including flue gas, low-temperature hot water, steam, and other channels.

- New materials technology may be utilized to improve the efficiency of heat operations by increasing radiation output from furnaces and boilers and boosting thermal conductivity performance.
- Technology for optimizing processes: Energy recovery and conversion efficiency may be improved by the use of novel techniques.
- With the use of process intelligence software, energy consumption throughout a whole plant may be optimized with the help of intelligent system scheduling technology.
- Energy-saving technology in the water-circulating system includes improvements to pumps, motors, and groundwater-cooling tower fans to better match water volume and lift with demand, therefore collecting and recycling circulating water's over-bottom pressure.
- Improvements in heat transport and combustion efficiency, as well as load regulation, are triggered by a suite of carefully selected additional pieces of equipment.

5.3 Hydrogen

One third of the world's total hydrogen consumption is anticipated to come from the refining sector alone. Figure 14 shows that although overall demand for hydrogen that is pure has climbed by a factor of almost four since 1975, demand in the refining sector has increased by a factor of more than six over the same time period. For example: (Sgouros, G.-A., and Digkas, Agis-Georgios. (2021). A promising link between Europe, the Middle East, and North Africa might be provided by blue hydrogen. countries adopting the Green Deal's policies.)

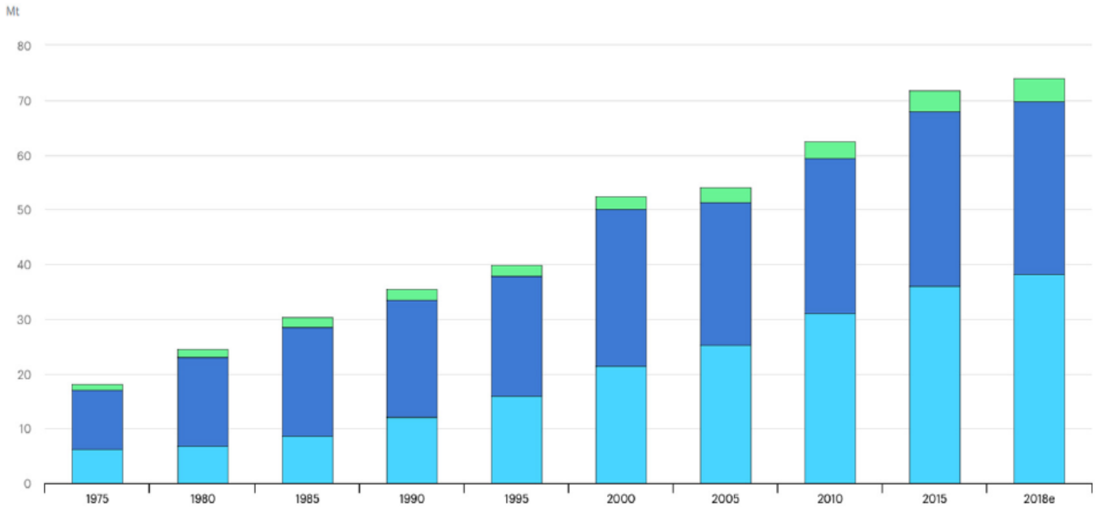


Figure 9. Global demand for pure hydrogen per industrial sector (“non-pure” hydrogen use not included), 1975–2018. Note: light blue: refining industry; dark blue: ammonia ; green: other). (Sgouros, G.-A & Digkas, Agis-Georgios., 2021).

The worldwide need for hydrogen in the refining sector is fulfilled by three main suppliers:

Production on-site as a byproduct of refining operations (known as naphtha reforming), production on-site from devoted unit processes (most commonly steam methane reforming, SMR), production off-site and purchase from specialized suppliers, and production on-site as a byproduct of refining operations (known as naphtha reforming).

Merchant hydrogen manufacturing processes are nearly solely dependent on conversion of fossil fuels or as byproducts of the chemicals industry, in contrast to specialized hydrogen production by electrolysis, which is primarily in the late demonstration and preliminary deployment phase. About two-thirds of the hydrogen used in oil refineries is either generated at specialized on-site facilities or purchased from merchant suppliers, since on-site hydrogen generation as an outcome of refining processes can only fulfill about a third of hydrogen demand. Hydrogen is employed largely in the hydro treating for light hydrocarbons as well as the hydrocracking of heavier distillates to produce more valuable petrol and diesel-range products inside the oil refining industry's

process activities. Hydrocracking and/or coking of residues, hydrotreating of biological oils for biofuels generation, and coprocessing using standard feedstocks are some further uses. The preference for heavier and lower quality crudes processing, in addition to increased demand for lower-sulfur fuels in the diesel range, has a beneficial impact on predicted demand for hydrogen in oil refineries (Griffiths S., Sovacooj B., Kim M., Bazilian M., Ursula Bazilian, and Ursula Ursula) (Griffiths, Sovacooj, Kim, Bazilian, Ursula, and Urs
Decarbonization for hydrogen consumption in oil refining may be accomplished in a number of different ways:

- "Blue" hydrogen created by carbon capture and storage (CCS) from steam methane reforming (SMR) of either natural gas or coal.
- Green hydrogen may be produced using low-temperature electrolysis with changeable renewable energy sources, such as sun, wind, biomass gasification, and biogas.
- Hydrogen with a low carbon footprint produced by nuclear-powered thermoelectric generators.

The "technology readiness level" of many new and groundbreaking technologies is low, meaning that they may not be able to be scaled up sufficiently to contribute significantly to global warming mitigation goals, which require immediate and well-joined actions. The rising interest in the generation of hydrogen with low carbon emissions for industrial uses is reflected in the number of projects now under development or contemplation. Hydrogen is possibly the most widely used of the energy vector solutions for industrial use decarbonization where direct electrification cannot be possible because of its attribute as a vector that can be converted into and from additional pertinent vectors, including electricity, ammonia, methanol, and synfuels. The use of hydrogen as a vector for energy is encouraged wherever feasible by a well-designed and -executed relationship between hydrogen and sustainable and low-carbon energy sources. Therefore, reducing emissions byproduct hydrogen is of critical necessity to accomplish through CCS, and rising demand for low-carbon hydrogen generation may fulfill oil refineries' demands for specialized onsite and merchant hydrogen production.

Because the lowering of emission associated with low-carbon hydrogen affects the first ones, the structure of the oil refining processes is another element that influences the decline of scope 1, 2, or 3 emissions. Independently or as part of actions in various hard-to-decarbonize sectors, selected initiatives aimed at the oil refining industry concentrate on the existing significant industrial consumers of hydrogen, refining, chemicals, steel, and iron, and pair these sectors with other related to energy applications, such as concrete and buildings, to offer an united vision of hydrogen-based periods of transition.

5.4 Carbon capture, utilization and storage (CCUS)

It is an undeniable reality that the refining business has several, widely dispersed sources of CO2 emissions, each of which emits a somewhat varying quantity of CO2. On the tide of circular financial thinking, prompted by environmental issues and with an eye toward rewarding carbon capture, the concept of converting CO2 into a useful feedstock has reemerged. The term "carbon capture, utilization, and storage" (CCUS) is used to describe a group of technologies that can each play a unique but crucial role in achieving international energy and climate targets. Point sources of carbon dioxide capture include power plants and factories that burn fossil fuels or biomass to energy. It is also possible to extract CO2 from the air. Compressed and transported for use in various applications if not used on-site; injected into deep geological formations that trap it for permanent storage (International Energy Agency - About CCUS, Playing an important and diverse role in meeting global energy and climate goals, 2021 https://www.iea.org/), (see Figure 15) (International Energy Agency - About CCUS).

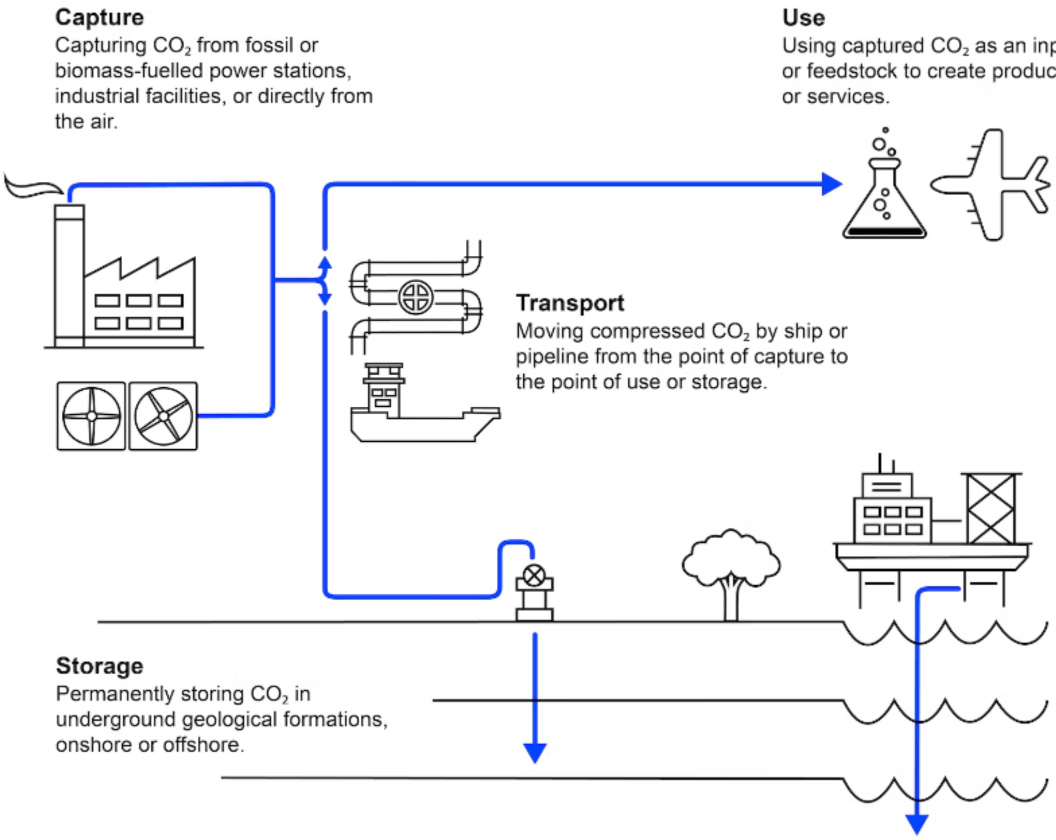


Figure 10. The CCUS process (International Energy Agency, 2021).

CCUS is gaining additional support as a result of stronger incentives for investment and climate ambitions. Industrial "hubs" have been designed to harvest CO2 from several sites using a centralized CO2 storage and transportation system, and there is a rising backlog of scheduled projects. Technologies that separate or collect CO2 have been available for usage for decades since the capture is a standard feature of many industrial processes.

Absorption by chemicals and physical separation are the most sophisticated and extensively used capture methods, but there are also membranes and loop cycles like chemical looping and calcium looping.

In order to transport carbon dioxide, reliable and secure infrastructure must be on hand. Large quantities of carbon dioxide (CO2) are often delivered by pipeline or ship, although smaller quantities may be carried by truck or train at a greater cost per ton. Once CO2 has been delivered, it may be utilized as a component in several end-markets.

Direct usage, where the CO2 does not get chemically transformed (non-conversion), and converting it to a useful product by biological and chemical processes (conversion) are both possibilities.

The next step in CO2 storage is injecting the collected volumes into a sealed geological reservoir located deep below, where it will not escape into the atmosphere. Deep saline deposits and depleted gas and oil reservoirs are the most capacious of the several reservoir types that are appropriate for storage. The available capacity to store carbon dioxide across the world is projected to far outweigh anticipated demands. Because CCUS's impact expands over time and touches almost every component of the world's energy system, the technologies behind it play crucial roles in the race to zero emissions.

To fulfill both present and potential demand from novel uses in transportation, industry, and buildings, CCUS can assist a quick scaling up of low-carbon production of hydrogen as one of the two major techniques to manufacture low-carbon hydrogen.

According to the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Carbon Dioxide Capture and Storage (2005), available at https://www.ipcc.ch/, three potential carbon capture systems are shown in Figure 16 depending on the unit operating location and emission steam.

- post-combustion,
- pre-combustion and
- oxy-fuel combustion.

However, in the post-combustion instance, the expenses and mitigation of CO2 potential of carbon capture techniques applied to various unit processes and utility systems vary greatly due to variations in the concentration of CO2 and flowrates of flue gases. Oxy-fuel combustion is preferred over precombustion in the catalytic cracking unit (CCU). The most cost-effective methods of deploying carbon capture include combined-cycle units, utility systems, and hydrogen SMR.

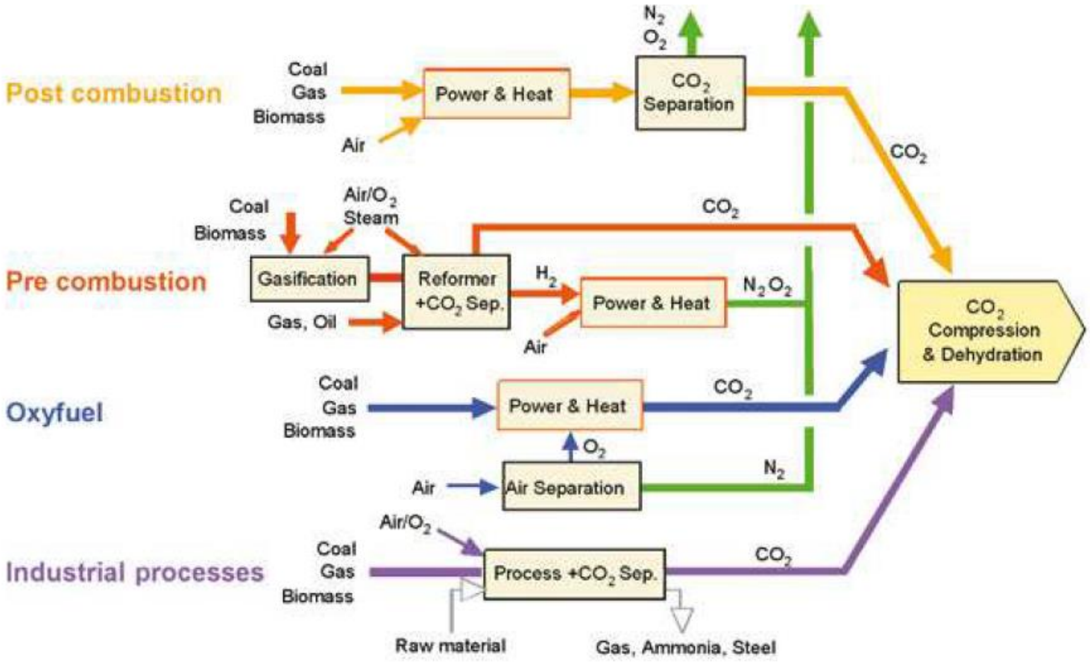


Figure 11. CO_2 capture technologies (IPCC, 2005).

5.4.1 Pre-Combustion

Before burning coal, oil, or gas to create energy, the CO2 is extracted from any industrial sources. Synthesis gas, which includes hydrogen along with carbon monoxide (CO), is created from the fuel first. The latter combines with water to generate carbon dioxide, which is collected, compressed, and stored independently of the hydrogen. The leftover hydrogen is burned to provide heat and electricity. At this stage, the capture technique can help cut CO2 emissions by 90–95 percent. Some refineries currently employ this technology, but most power plants have yet to catch up. CO2 collection uses Fluidized Bed Combustion (FBC) and Integrated Gasification Combined Cycle (IGCC) technologies. To begin, one technique is used to decrease emissions from power plants while increasing energy generation. Before being burned at low pressure using a physical or chemical solvent, carbon is collected using IGCC technology. In this method, fossil fuels are broken down into their component parts—carbon dioxide (CO2) and hydrogen gas (H2)—before being separated. Though pre-combustion technology is primarily applicable for newly constructed power plants, it has poor efficiency results for current facilities, so it should be examined further before its incorporation into the production process (Intergovernmental Panel on Climate Change - Special Report on Carbon Dioxide Capture and Storage, 2005, p. 5). The percentage of CO2 that can be eliminated from an energy facility by pre-combustion capture of carbon dioxide using IGCC technology is quite high, reaching about 90%.

5.4.2 Oxy-fuel combustion technology

In order to trap carbon dioxide during combustion, the coal is burned with very pure oxygen (>95%) rather than air. The combustion process generates a flue gas rich in concentrated carbon dioxide (CO2) as well as water vapor, both of which may be easily extracted after being cooled. Condensation of the water produces a CO2 heavy gas stream. Since the oxy-fuel process can successfully remove up to 100% of CO2 out of flue gas, it is a very efficient method. The primary issue with this technology is the energy penalty it imposes on the power plant due to oxygen separation from the air. To accommodate the additional, substantial quantity of energy that CCS requires for consumption, the "power generation cycle" is used; this is the process by which less energy is generated than is needed or more energy is needed as input to produce the same amount of energy. According to a 2012 review of technologies for reducing CO2 emissions from coal-fired power plants (Moazzem S., Rasul M.G., and Khan M.K., A Review on Technologies for Reducing CO2 Emission from Coal Fired Power Plants, https://www.intechopen.com/), the amount of energy required by CCS is known as a "energy penalty," and it eventually contributes to higher cost of power production.

5.4.3 Post-combustion CO_2 capture

Post-combustion CO2 capture is the last opportunity to separate and remove carbon dioxide after air and fuel have been burned to create electricity but before the exhaust gas hits the stack. Its main benefit is that it can be retrofitted into older facilities with little disruption. Having the required capturing equipment in place is the only other need. After combustion, CO2 may be captured in a number of different ways. Chemical absorption with amine solvents is the most widely used post-combustion method (Moazzem S., Rasul M.G., and Khan M.K., A Review on Technologies for Reducing CO2 Emission from Coal Fired Power Plants, 2012, https://www.intechopen.com/).

Other methods include membrane technology, the PSA (pressure swing adsorption) process, and mineral carbonation.

5.5 The Net Carbon Footprint Model

Businesses in industries responsible for the vast bulk of this form of pollution have also warmed up to the idea of reducing their carbon footprint, which has been addressed seriously by municipal governments and the European Union. Since they are responsible for the phenomena, it is up to them to provide workable strategies for achieving the "Net Zero" goal by 2050.

The Dutch oil market leader Shell has announced plans to lower the carbon footprint of the company's energy product range by 20% by 2035. This statement from 2017 introduced a methodology called the "Net Carbon Footprint" (NFC) model, (Shell Global Solutions Inc., 2021 https://fourleafdigital.shell.com/) designed to apply to product categories spanning from liquid fuels for transportation to pipeline gas and LNG for power to the transportation and power of electricity generated from renewable resources. It was unarguable that in order to fulfill such a lofty pledge, it would be necessary to first keep tabs on and quantify all emissions of greenhouse gases throughout the whole product life cycle, including not just in-house creations but also those procured from other sources. As a consequence, a technique was devised to determine the Net Carbon Footprint of items from the point of sale to their final consumer's usage (in gCO2 per Mega-Joule). Now it's evident that the NFC model doesn't include non-energy items like lubricants and chemicals since their final use isn't as a fuel.

5.5.1 Overview of the methodology

NCF is determined by analyzing the emissions intensity of the company's product supply chains. To get to the point of extracting findings, a method based on reviewing the principles of the existing lifecycle analysis has been used. This method takes into account not only the emissions connected with the end goods that are released to the market, but also the emissions that come from their usage. (Refer to Fig. 17) The total NCF is calculated by excluding emissions absorbed in sinks and averaging the supply chain intensity measurements into a portfolio median weighted by the provided energy.

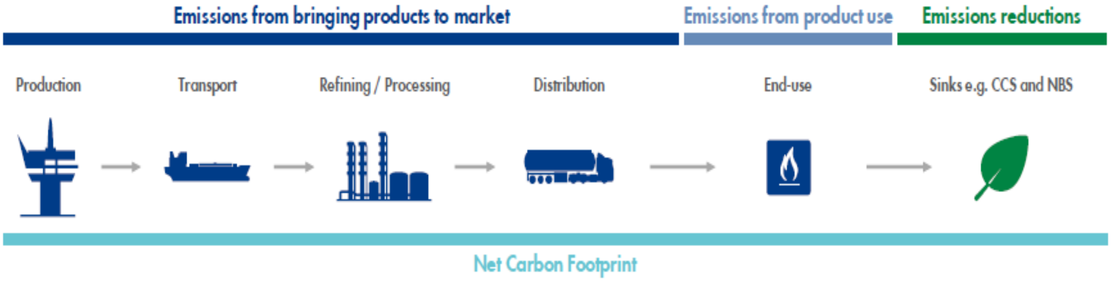


Figure 12. Indicative supply chain – an illustration of the emissions sources and sinks of the Net Carbon Footprint (The Net Carbon Footprint Model: Methodology, Shell Global Solutions UK, London, 2021).

Since NCF is linked to the entire life cycle of each energy product, including the process phases of transporting and converting the product towards the end user, the level is determined on the entire greenhouse gas the lifespan emissions of a product, making the point in the supply chain where the sale is made irrelevant. By this definition, only net actual transfers are accounted for, while all other forms of commodities trade are disregarded. According to the tenets of this approach, the company's obligation for the NCF ends after the items have been successfully delivered to the ultimate client, and the products' subsequent destiny is no longer in the company's hands.

5.5.2 Scope of NCF analysis

The whole manufacturing process, from sourcing raw materials to delivering finished goods to consumers, as well as any disposal or waste streams generated along the way, must be included into a product's lifetime emissions assessment. This approach emphasizes the fact that a company's equity is determined only by operating emissions and not by emissions associated with the production, transport, or disposal of fuels or end-use facilities. The publicly accessible data and information are contested as to their reliability and trustworthiness, and the additional energy needs of the whole fuel pathway have little effect in terms of amortization, across the entire lifespan of the facilities engaged. The scope of the procedure includes calculating the Net Carbon Footprint of every energy product sold, which may include components manufactured or processed either in-house or by other parties. Due to the varying nature of the inputs from outside sources, the intensity is evaluated from three angles: manufacturing, distribution, and retail.

Energy products are divided into two categories inside an oil company: those created in-house, known as "production," and those made, known as "processing," utilizing either in-house or external feedstocks.All energy items, whether made in-house or purchased, count toward the company's overall revenue.

Although not all emissions can be traced back to the well, the NCF approach utilizes the phrase "well-to-wheel" emissions to define the lifetime emissions of a product. As was previously indicated, the delivery of energy-related goods to power providers, as well as emissions linked with the manufacturing and distribution of fuel to the company's assets, are not included. In reality, the NCF measure is unaffected by the exclusion of some kinds of emissions on an annual basis and changes occurring during this time in the quantity of energy products, as the main focus of the technique is to react to shifts in the company's portfolio and activities.

5.5.3 Functional units

Since the intensity of a product's lifespan is difficult to pin down, comparable products must be defined in terms of similar metrics. Given the wide variety of applications, it is difficult to standardize on a single metric for evaluating a product's value to the consumer. Oil products, for instance, have many applications in transportation, and the value they provide to consumers is often expressed in terms of the distance or weight they enable a vehicle to convey. Since natural gas is mostly utilized for producing electricity and heating homes, its primary benefit to consumers is the energy it provides. The end-use functional unit of consumption of energy has been accepted by the NCF methodology. A natural gas pipeline's lifecycle carbon intensity, for instance, is measured in grams of carbon dioxide equivalent per megajoule and includes emissions from end-use burning of greenhouse gases. While the technique does account for combustion emissions, separating them out on the basis of vehicle type or efficiency is outside its purview.

5.5.4 The Oil portfolio

The NCF calculation for oil portfolio products is applied for a variety of metrics as listed below:

- Intensity of annual oil production measured in kilograms of carbon dioxide equivalent per barrel of oil equivalent.
- Annual oil output is listed in kilobarrels of oil equivalent per day.
- The number of kilometers from the pipeline to the shipping terminal.
- Efficiency of the refinery stated as a ratio of crude oil to finished goods produced.
- The refinery's "diet," the fraction of its crude supply that comes from each of as many as 40 different nations.

Figure 18 shows the oil supply chain from the refinery to the selling point as well as the final use efficiency (tank to wheel), all of which must be taken into account when calculating the whole-life intensity of oil production.

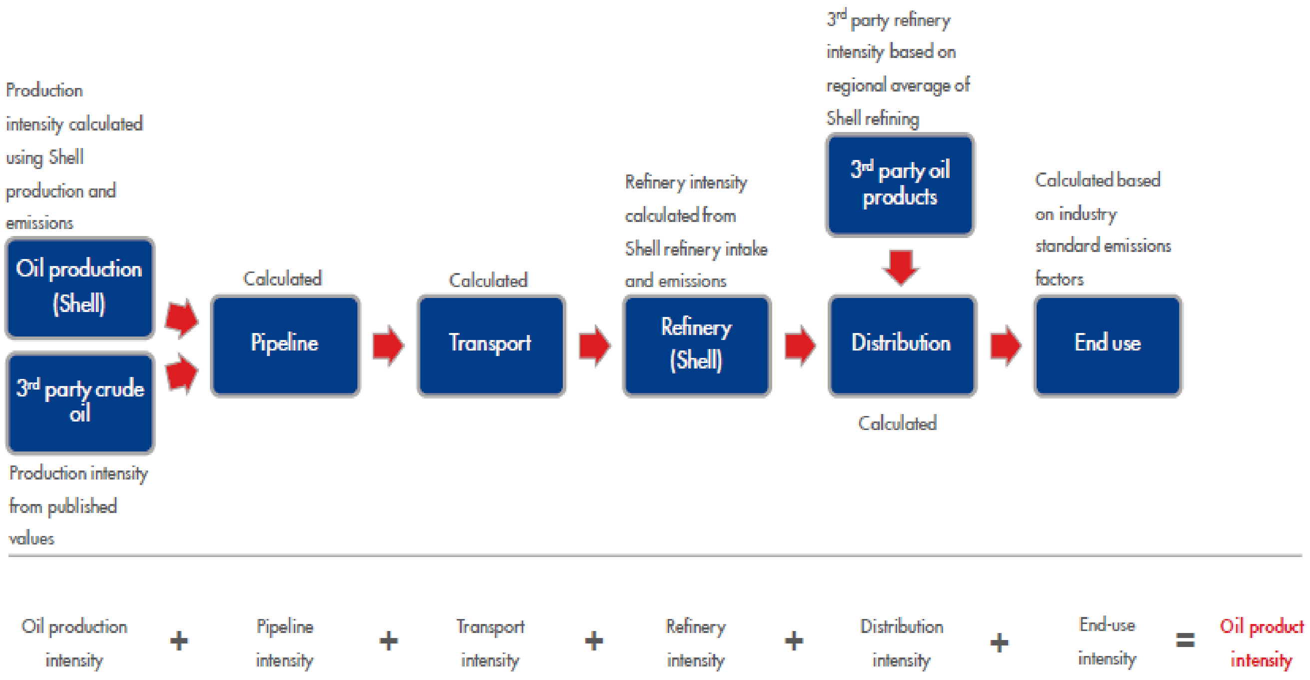


Figure 13. The Oil supply chain (The Net Carbon Footprint Model: Methodology, Shell Global Solutions UK, London, 2021).

Both corporate crude oil and crude oil from third parties refined by the firm are included in the processed computation for the oil portfolio. Refineries' caloric intake and output rates are used to estimate the quantity of crude oil each producing nation must provide. Final supplied energy is proportional to the quantity of oil treated in the refineries, and the oil processed computation is controlled by a list of exclusive refinery assets. If a nation doesn't produce enough oil, the corporation may supplement its supply with oil from other countries, or vice versa.

The subsequent phase in the sequence is the computation of oil sales, which is influenced by an array of oil sales by area, outlining the final supplied energy in every one of those regions. Reports are kept and the sales amount of refined items is recorded. Because each crude source included in the refinery diet is classified as 100% non-corporate crude, identifying who exactly is producing the oil is crucial. One country per area is used as a proxy for measuring oil transport distance, and the intensity from well to wheel is calculated appropriately.

5.5.5 Conclusion of NCF methodology

Method that is both adaptable and business-focused, taking into account not only the technical details of an item or procedure but also its significance in the context of the company's overall operations and its ultimate goals. The direct emissions' decrease of the entire portfolio with proactive measures and a continuously processing manufacturing process and well-designed transportation offers significant value to both the producer/seller of energy-related goods and the end-user/customer, as an advantageous transaction through an everyday standard business process among the industry. It is possible to quantitatively compare the success of various businesses, departments, production phases, national marketplaces, and product lines. Business demands of such an organization in the oil refining sector are met by numerical data provided by mathematical computations, which result from the transformation from qualitative information into quantitative data.

Finally, as an internal overview from its efforts to achieve net zero emissions, the Shell company has published some helpful and interesting figures related to greenhouse gas emissions, from the years 2020 and 2021 (Shell Global Solutions Inc., The Net Carbon Footprint Model: Methodology, 2021 https://fourleafdigital.shell.com/; see Figure 19).

- Compared to the stated 63 million tons of GHG emissions in 2020, the actual GHG emissions from operating facilities (Scope 1 emissions) were 60 million tons of CO2 equivalent in 2021.
- In 2021, there will be an increase of 0% from 2020 levels of indirect greenhouse gas (GHG) emissions from energy-related activities acquired (electricity, heat, and steam), emissions pertaining to Scope 2. The market-based technique, as specified by the World Resources Institute GHG Protocol, was used to determine these emissions.
- Scope 1 direct equity share GHG emissions decreased from a total of 98 million metric tons of CO2 equivalent in 2020 to 91 million tons in 2021.

- In 2021, the Scope 2 indirect GHG emissions from equity investments were 9 million tons of CO2 equivalent, the same as in 2020.

Scope (million tonne CO_2 equivalent)	**Operational Control - 2020**	**Operational Control - 2021**	**Equity - 2020**	**Equity - 2021**
Scope 1	63	60	98	91
Scope 2 (market-based method)	8	8	9	9
Scope 2 (location-based method)	10	9	10	10

Figure 14. Shell company’s GHG emissions (Scope 1 – Scope 2) breakdown during 2020 & 2021 (The Net Carbon Footprint Model: Methodology, Shell Global Solutions UK, London, 2021).

- Figure 20: Greenhouse gas (GHG) emission intensities for operationally controlled Upstream and Integrated Gas, refining, and chemical plants (100 percent of direct Scope 1 and energy indirect Scope 2 emissions provided).

(A) Equivalent tons of greenhouse gas emissions from Integrated Gas and Upstream's oil and gas production, LNG exports, and gas-to-liquids conversions.

(B) Ethylene and propylene are examples of olefins, which are produced together with other high-value compounds including benzene, , acetylene, and butadiene,high-purity hydrogen.

(C) Solomon Associates has developed their own internal measurement called UEDCTM (Utilized Equivalent Distillation Capacity). It is a normalization parameter that takes into account the refinery's complexity and size to determine how much it will cost to run the refinery's various processes and support facilities.

Emissions Intensity	Units of measure	2020	2021
Upstream and Integrated Gas [A]	Tonne CO_2 equivalent/tonne of hydrocarbon production available for sale	0.159	0.172
Chemicals [B]	Tonne CO_2 equivalent/tonne of stream cracker high value chemicals produced	0.98	0.95
Refineries [C]	Tonne CO_2 equivalent/UEDCTM	1.05	1.05

Figure 15. Shell's emission intensity for Upstream and Integrated Gas, Chemical and Refineries during 2020 & 2021 (The Net Carbon Footprint Model: Methodology, Shell Global Solutions UK, London, 2021).

5.6 HelleniQ Energy – VISION 5050

Established in 1988, HelleniQ Energy has grown to become one of Southeast Europe's most prominent energy companies, with a footprint in six different nations and interests covering the whole energy value chain. The three Greek refineries run by HelleniQ Energy—in Thessaloniki, Elefsina, and Aspropyrgos—constitute 57% of the country's total refining capacity. Owns the OKTA oil product distribution terminals in Skopje, Republic of North Macedonia. Saudi Arabia, Iraq, Iran, Libya, and Russia all provide crude oil to the refineries. More than 1700 gas stations are run by the corporation in Greece under the BP and EKO labels, while another 300 are spread throughout Serbia, Bulgaria, Cyprus, Montenegro, and the Republic of North Macedonia. It also features a distribution system for liquid petroleum gas, aviation fuel, naval fuels, and lubricants. HELLENIQ ENERGY Group is committed to reducing carbon dioxide (CO2) emissions from refineries in accordance with European Union (EU) law (https://www.helpe.gr/), reflecting widespread concern about climate change and the EU's goal of achieving an economy that is carbon-neutral by 2050.

HELLENIQ ENERGY Group has helped to prepare an extensive proposal by the European Sector for Refining transition, titled "Vision 2050," as an active member of "FuelsEurope," the Association which represents in the European institutions the needs of the 40 refinery companies in Europe. This report investigates how EU refineries may be turned into energy centers for energy and low carbon products, which would be vital for a climate-neutral economy and society, and it is the first proposal already made in 2018 by the Industrial Sector to the European institutions. To help combat climate change and advance energy transformation, HELLENIQ ENERGY Group has set a long-term objective (Figure 21) of becoming a supplier of low-carbon energy solutions and halving its carbon footprint by 2030. As so, the "refinery of the future" is now open for business, promising to create cutting-edge technologies while using novel raw materials, sources of sustainable energy, hydrogen, and recovered CO2. As an added bonus, the firm opens the way for the manufacture of clean fuels, which is a response to the demand for lower carbon emissions across all modes of transportation and contributes to the EU's lofty climate neutrality goals.

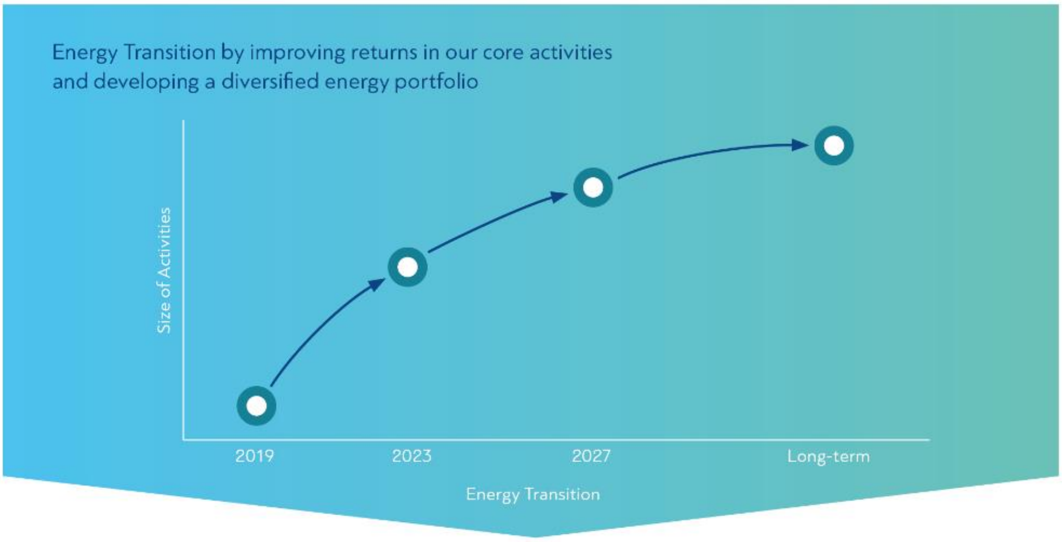


Figure 16. Vision & Group Energy Transition Strategy (HELLENIQ ENERGY Group).

The Group maintained its outstanding operational performance across all three refineries during 2020, despite the obstacles provided by COVID-19, and successfully executed the entire reversal of the Aspropyrgos refinery in the second half of the year. Large sums were spent on upgrades throughout the turnaround, the majority of which went toward greener practices and increased security. The Group's overall goal is to reduce its negative impact on the environment by taking measures like increasing the use of fuel gases, switching to fuels with stricter environmental standards, and incorporating cutting-edge technologies into the manufacturing process to cut down on waste and emissions. Since 2020, the Aspropyrgos, Elefsina, and Thessaloniki refineries will all be required to have new environmental permits that include all measures necessary to reduce their environmental impact and bring them into line with the latest emission standards based on the Best Available Technologies (BAT). In particular, Aspropyrgos, a high-complexity FCC-type refinery constructed in 1958 and widely regarded as one of the most advanced refineries in Europe, has undergone a number of upgrades, the most notable of which was the 2019 finish of the transition of the gasoline blending sections MTBE and TAME manufacturing units into ETBE as well as TAEE production units, allowing the refinery to begin producing bio-ethers. on order to better the environmental impact and quality of the end product and to replace imports, HELLENIC PETROLEUM Group has made adjustments to ensure that they can continue to offer E5 gasoline on the local market without adding any bioethanol. The Aspropyrgos refinery's full turnaround was accomplished in the latter half of 2020. While the Group completes projects of a similar kind across all of its refineries, the scale, complexity, and sheer quantity of personnel and contractors engaged in this specific project made it very difficult to accomplish on schedule. Budgeting more than €130 million, it was the Group's most expensive project ever. Over fifty percent of the budget went into safety and environmental modifications, and overall particulate matter (PM) emissions from the refinery are predicted to drop by fifty percent as a result (https://m.helpe.gr/).

5.6.1 Government Decision for Renewal / Amendment of Aspropyrgos Refinery.

The Hellenic Ministry of Environment and Energy made a formal announcement in December 2019 (Decision No. /A/111789/6831-02/12/2019) (https://ypen.gov.gr/) regarding the improvement of the Aspropyrgos facilities in connection with the establishment of environmental terms and conditions for the refinery.

To accomplish this goal of reducing VOC emissions by 95% and recovering gasoline vapors produced during loading and unloading operations, it was proposed that a new Vapor Recovery Unit (VRU) be installed and operated at the ports' refinery amenities, with a maximum gasoline product flow rate of 3,700 m3/hour. The new VRU is a hybrid absorption system that works by first absorbing H/C vapors into activated carbon, and then using gasoline flowing in the opposite direction from a storage tank to soak up the vapors. Hydrocarbon and benzene concentrations in the continuously exhausted air are being monitored by analyzers included into the new VRU unit's ventilation system. Automatic system operation is expected to guarantee at least four analyses per hour in the event of analyser downtime.

In order to cut down on nitrogen oxide (NOx) emissions, another novel intervention is being considered: the use of gas turbines as well as boiler E (De-NOx project, harmonisation with new standards for emissions, BAT 57, Executive Decision 2014/738/EU). This involves 1) replacing a gas turbine, 2) employing the fuel mixture (gaseous fossil fuels for refinery self-consumption - Fuel Gas and natural gas), and 3) replacing the old burners in the boiler that used Fuel gas (self-consumption fuel) with new burners that use Fuel Oil and Fuel Gas and produce fewer nitrogen oxides. According to the plan, particle emissions may be lowered by 37.5 percent (De-dust project, conformity with new emission limitations, BAT 25, Executive Regulation 2014/738/EU) if an electrostatic precipitator (ESP) is installed in the FCC Catalytic Cracking Unit (U-4100), which processes flue gases before the stack.

To achieve sustainability inside a refinery and to implement measures with lower greenhouse gas emissions, the aforementioned modifications are substantial and radical.

No CO2 emission limits are set (Article 21), nor are requirements on the energy efficiency of combustion units that emit carbon dioxide coal (https://www.hellenicparliament.gr/) because the refinery comes in the scope of K.Y.A. 54409/2632/04 as incorporated into the national law with the K.Y.A. 181478/965/17 (Government Gazette 3763B).

Under normal operating conditions, the following emission limits (Sources and Quantities of atmospheric of pollutants, Annex 2 of the Decision) must be observed, based on Executive Decision 2014/738/EU and Best Available Techniques for oil and gas refining ((BAT), Reference Document for the Refining of Mineral 2015):

All of the stacks from the refinery units using integrated emissions management (bubble concept, compliance with BAT 57 and BAT 58, Executive Decision 2014/738/EU) must emit less than or equal to the following: A) SO2 and NO2 emissions with an average monthly content of O2 up to 3% on dry basis.

B) Carbon monoxide emissions from the stacks of the refinery units at less than 100 mg/Nm3 on a monthly basis (in line with BAT 37, Executive Decision 2014/738/EU).

C) Emissions of hydrogen sulfide (H2S) from the stack of the Sulfur Recovery Units, on an average day: 10 mg/Nm3.

Dust from gas turbine stacks (D), with an average daily O2 concentration of 15% on a dry basis and a particle size of 5 mg/Nm3.

E) Gasoline vapour recovering system discharge (adherence to BAT 52, Commission Decision 2014/738/EU): Benzene emissions 1 mg/Nm3, volatile organic compound emissions 10 g/Nm3.

It is also emphasized that it is critical to monitor and report the following parameters about the refinery's overall ambient air quality:

- Sulfur Dioxide (SO2), with hourly average annual values of 350 g/m3 and an exceeding range of twenty-four times per calendar year, and with daily average yearly values of 125 g/m3 and an exceeding margin of three times per calendar year.
- NO2: 200 g/Nm3 for yearly average hourly values, with an overage of eighteen times every calendar year and 40 g/m3 for yearly average price.

Over a three (3) hour period, the alarm limits for NO2 and SO2 are 400 and 500 g/m3, respectively.

- Benzene, carbon monoxide (CO), and ozone (O3), all as those terms are used in the aforementioned K.Y.A.
- Polycyclic Hydrocarbons (as specified in the requirements of the aforementioned K.Y.A.), Arsenic (As), Mercury (Hg), Cadmium (Cd) and Nickel (Ni).

According to the Group company's "Annual CSR report - 2021" (https://sustainabilityreport2021.helpe.gr/), all of the aforementioned actions and efforts are in accordance with the projected reduction, which corresponds to a 50% drop in carbon footprint by 2030. By 2050, this goal will help the corporation become carbon neutral and aid in mitigating climate change's causes and effects. Figures 22 and 23 show the specific targets the company has set for itself: • a reduction of Scope 1 & 2 emissions by more than 30% via energy use optimizing and the utilization of innovative technologies for lowering GHG emissions in its refining activity; and • the further development and implementation of expenditures in energy from renewable sources (RES) resulting to the offset of more than twenty percent of CO2 emissions.

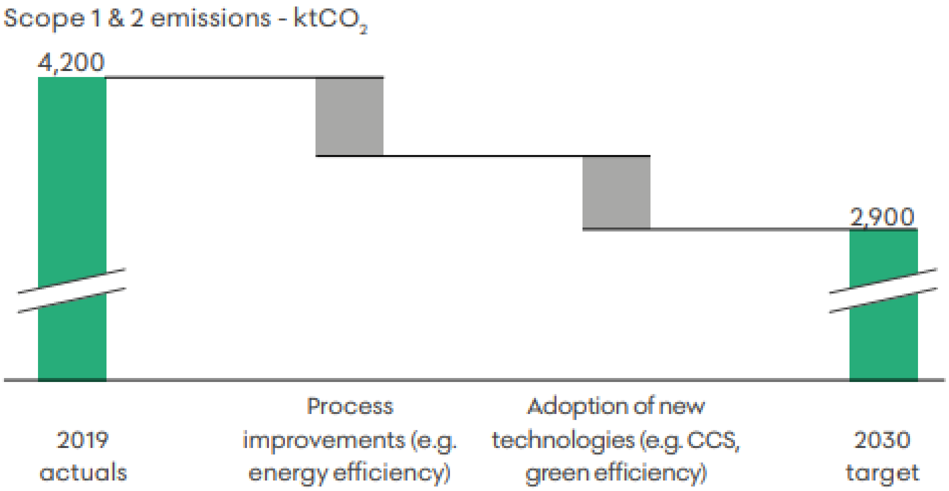


Figure 17. Reduce scope 1 & 2 emissions by 30% (HELPE, CSR Report 2021).

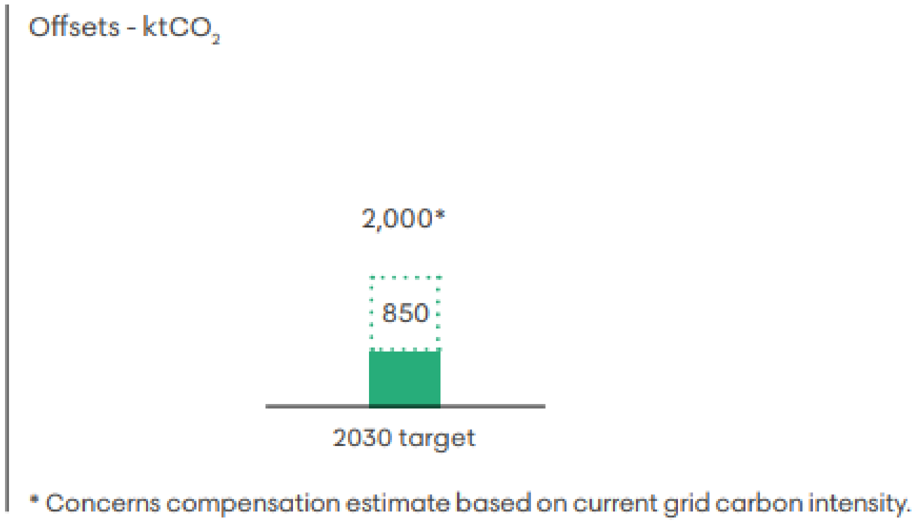


Figure 18. Offset an additional ~20% of emissions via RES (HELPE, CSR Report 2021).

With respect to CO2 emissions monitoring and reporting, the Group routinely tracks not just direct emissions (Scope 1) as well as indirect emissions (Scope 2 and 3) across a significant portion of its operations in line with the GHG Protocol technique, a further certification according to the ISO 14064 international standard being obtained for the activities in Greece beginning in 2020.

Three EU ETS-participating refineries have confirmed direct emissions (Scope 1) of 3.7 million tons of CO2 for 2021 quantitative data, and the Group as a whole (headquarters and all subsidiaries) has indirect emissions (Scope 2) of 455 thousand tons of CO2 from its electricity use.

It is worth noting that the Group's refineries have been active participants in the European Greenhouse Gas Emission Trading System (EU ETS) ever since their inception, and that they strictly adhere to all the procedures for the monitoring, calculation, and validation of emissions to comply with the 2021-2030 Phase 4 Regulations, which are even more stringent than the previous phases.

It should be noted that the cost for complying for Phase 4 ETS has increased significantly due to the increasing goals for reducing emissions at the European level, the reduced proportion of free carbon allowances assigned to all refineries in Europe, and resulting significant increase in the price of carbon allowances in 2021 (going from the €30/tn. range to more than

€80/tn.). In order to illustrate the dramatic rise in the emissions carbon allowance deficiencies between the third phase (year 2020) and the fourth phase (year 2021) of the ETS and the associated compliance costs, the following chart (see Figure 24) shows the complete proved CO2 emissions of the Group's three petroleum refineries for 2020 and 2021 (for comparison), along with the corresponding free carbon allowances.

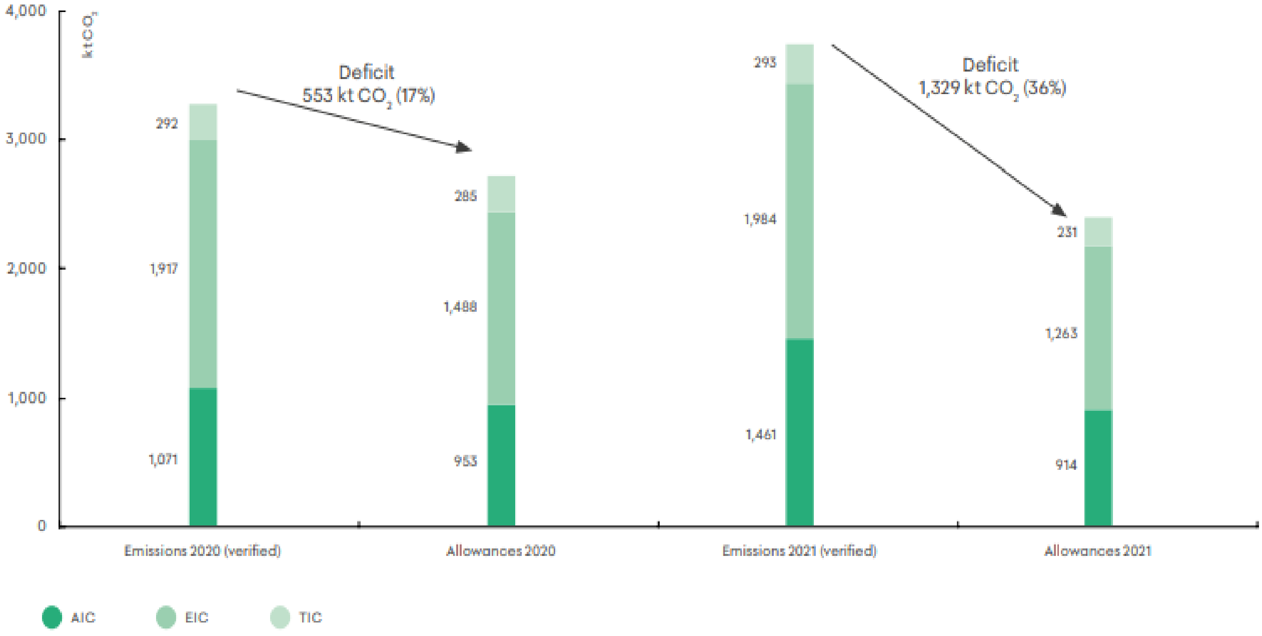


Figure 19. Verified emissions and free CO$_2$ Carbon allowances for the group’s three refineries in 2021 (HELPE, CSR Report 2021).

CHAPTER 6: CONCLUSIONS

Carbon footprint is a concern of high importance during the last years, more than ever, since it affects societies, economies, industries and individuals at any level.

There have been performed several attempts to measure it, with an upper goal to mitigate it and reduce the greenhouse gas emissions that compose it. This "exercise" sounds simpler than it is, since it is a multifactor challenge to successfully track the sources of emissions and at the same time design solutions for their reduction or extermination.

Challenges around definition of carbon footprint, types of emissions, the available technology for accomplishing reduction, the legal framework based in directions such as those coming from EU, the strategies behind governmental and corporate decisions in a specific industry, are some of the major questions that need to be examined in order to proceed into a decarbonization path.

Oil refinery industry remains a key-emitter, so part of its strategy is to find out and perform solutions that will lead to net-zero condition. The sustainability-oriented methods, followed by many companies, are described in depth in this Thesis, a breakdown analysis that is able to introduce a new era of oil refinery industry, by unlocking production processes, ensuring effective results measured financially, technically and with "ESG" criteria. The later ones are those who drive or unlock decisions made by most of shareholders nowadays, therefore a refinery company is under investigation for its results towards this balance.

The strategies for reducing CO_2 emissions in a petroleum refinery include production of valuable products via CO_2 capture & storage, and heat and water recovery from refinery flue gases. Identifying the two strategies requires successive steps, such as, the direct CO_2 emission points that are analyzed through process simulation, an analysis from which, crude distillation units and steam plants are identified as the major emission sources. Regarding CO_2 capture, several products can be produced from the CO_2 sources, and it is found that there is an existing- potential to reduce CO_2 emissions and boost profitability by this method. Regarding water and heat recovery, an opportunity comes with reduction of both fuel consumption and cost as well by using the refinery flue gases and a hot waste gas stream. Nevertheless, some significant challenges remain in the design of an optimal process, and an optimization-based approach.

Although utilization of CO2 technologies are now commercially available, they cannot remove enough carbon dioxide (CO2) from the atmosphere to ensure the planet's long-term stability. If the market conditions are favorable, using CO2 might be cost-effective. Finally, the social component of CO2 mitigation measures in refineries has to be considered, as well as to the enviromental and economic trade-offs. An essential step in this direction will be the construction of legal and organizational frameworks that make it possible for the refining sector to make a sustainable conversion to net-zero, as well as the control over the costs involved with making this transformation.

CHAPTER 7: FUTURE RESEARCH TOPICS

The findings of this thesis and the discussions above suggest many avenues for more study.

The wide range of information and approaches offered in this Thesis might serve as a springboard for further study.

Using the latest tools and technologies available in the sector, it would be wise to investigate the discovered resources further and their impact on greenhouse gas emissions. The significance of the resulting analysis would rise as a consequence.

This Thesis identified the most pressing and plausible carbon footprint management concerns and proposed actionable solutions. There is no thought given to potential issues with these implementations that may result from these other approaches.

Since these interventions are relatively novel, future study may want to investigate how they might be implemented more precisely or efficiently.

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