Parting the Fog of War: Assessing Military Greenhouse Gas Emissions from Below

ABSTRACT

The world's militaries account for up to 5.5% of total global greenhouse emissions, yet there is still no requirement for governments to report these emissions in international climate agreements. Researchers are therefore left on their own to assess military emissions. This may seem like an incredibly daunting task. The lack of data is even more stark during periods of conflict, where reporting is relatively non-existent. This article sets out a novel framework for examining greenhouse gas emissions from military supply chains including situations where emissions data are difficult to acquire due to supply chain complexity, or when data are purposefully held back under the guise of national security. We provide an empirical study of supply chain-based carbon from the US military's use of concrete during the Second Iraq War (2003-08) to demonstrate its practicability. Concrete has a massive carbon footprint, and the US military uses a lot of it for protective walls, checkpoints, bases and bunkers. This work provides the tools to measure carbon embodied in military supply chains reinforcing recent calls for standardised frameworks emphasising the accounting of military environmental infrastructure footprints.

Keywords: Military Emissions, Greenhouse Gasses, Climate Change, War, Life Cycle Assessment

Highlights

- The procurement process of militaries, particularly during war time can be complex and secretive, which makes access to data needed to conduct Life Cycle Assessments (LCA) difficult to obtain.
- Our framework uses a whole supply chain LCA to measure the carbon emissions from concrete used by the US military during the Iraq war.
- Our results show that the combined emissions of T-walls alone used in Iraq came to 54.8 thousand tonnes CO2e, which is equal to 12, 782 gasoline-powered US passenger vehicles driven for one year.
- These findings are useful to overcome the secretive nature of military supply chains and calculate carbon emissions and social and environmental impacts during war and occupation.
- These calculations point to the urgent need for mandatory military emissions reporting for both war and peacetime through the UN Framework Convention on Climate Change (UNFCCC).

1. Militaries long war on the climate: Using Life-Cycle Assessments (LCA) as a tool for carbon calculations from below

The purpose of this article is to demonstrate that the amount of carbon embedded in complex military supply chains can be computed using Life Cycle Assessment (LCA) procedures providing evidence to support emission reporting in international climate agreements. In doing so, we shed light on emerging literature on global militaries' massive environmental footprints, particularly their hidden carbon emissions during war (Bun et al. 2024; Neimark et al. 2024; de Klerk et al. 2023).[1] The US military is one of the largest single institutional carbon emitters on the planet – according to Belcher et al. (2020) contributing more greenhouse gas emissions than over 150 countries, while Parkinson and Contrell (2022) show that militaries contribute up to 5.5% of all global carbon emissions. However, these calculations are never exact because, comprehensive data from military sources are never fully reported in international climate agreements (Rajaeifar et al. 2022; Crawford 2022). The problem of obscurity on military emissions reporting is one that impacts not only climate change researchers, but also advocacy groups working to address environmental justice, grassroots demilitarisation campaigns, public employees drafting ecological and environmental impact reports, and labour organisers concerning worker health (Elinoff and Rubaii 2025). Standard approaches for computing the environmental impacts of human activities such as LCA are constrained by data deficits, which leaves major gaps in knowledge about sectoral contributions to global greenhouse gas (GHG) emissions. Without an adequate baseline that includes accurate calculations of military emissions, meaningful international emissions reduction targets cannot begin in earnest. In our minds, the omission of such potentially large emissions data from global militaries is simply not an option. In response, we provide a novel toolkit for grassroots activists, academics and others, to conduct their own carbon analysis, thereby, demystifying the process for those who wish to use the tools of LCA. Our approach is also novel in that we integrate LCA data with qualitative responses from those who live and "breathe" the carbon emissions. Researchers could find the complexity of military supply chains very overwhelming, and coupled with the scarcity of data, could have trouble computing carbon emissions (Sharma, 2023). This article breaks the complex supply chains into phases, details the potential sources of carbon in each phase, and provides guidance on how to compute the amount of carbon embedded in each of the phases. We are of the view that, this is a major methodological and analytical contribution to the field of carbon accounting and efforts to decarbonise global militaries.

Our focus on the supply chain of concrete during the second US war in Iraq (hereafter referred to as the Second Iraq war - 2003-08), [2] is meant to open a "black box" of military carbon emissions during wartime – up to this point, a subject rarely addressed by climate scientists. This "fog of war" —that is both the particulate-filled emissions themselves and the

[1] See also de Klerk et al.'s 2024 framework on wartime emissions including many aspects usually left out of conflict emissions calculations.

[2] We note that this name reflects a US and European perspective, and that from an Iraqi this might be understood as the Second American War.

obscurity of military activity— can be circumvented by independent research. We provide an empirical study of supply chain-based carbon from the US military's use of concrete during the Second Iraq War to show researchers it can be done. The US military's counterinsurgency strategy in Iraq relied on hundreds of kilometres of concrete barriers for neighbourhood separation allegedly to safeguard civilian populations and control the movement of opposing forces (Izady 2020; Murrani 2016; Dumluji 2010; Rubaii 2022). The most common concrete barrier laid were the "Texas barrier" or "T-walls" which stand around 3.6m high and weighing 900 kg, vital in the protection for diplomatic and military installations against improvised explosive devices (IEDs), rockets, and mortar-fire (Neimark et al. 2024). It was during the occupation and counterinsurgency stages of the US invasion that T-walls were first introduced as a broad-spectrum of warfare technology. The social and ecological consequences of this strategy had lasting impacts on not only shaping supply chains of war but also on Iraq's landscape and society, such as segregating neighbourhoods, facilitating violence and sectarian cleansing, and generating new and more extensive traffic patterns (see Rubaii 2022).

T-walls provide a model case study of how to navigate the unseen terrain of military carbon emissions data by uncovering "hidden" greenhouse gases that go unreported. Globally, the concrete industry (including cement production and aggregate mining) has an enormous carbon footprint – an estimated 7% of total global emissions mainly from the of heat and energy in kiln-roasting to make cement, the main ingredient in concrete (Nature 2021) – and the US military uses a lot of it, from bases and bunkers to roads and airstrips. The dramatic increase of urban warfare over the past 20 years in Iraq and Afghanistan, has led to concrete being described as "…one of the most effective weapons on the modern battlefield" (Spencer 2016).[3] In addition, urban warfare accelerates the cycle of civilian concrete consumption, as bombed and destroyed building require reconstruction, thereby compounding the total emissions (Rubaii 2022). A study by Abdelnour and Roy (2024) found 32 million tonnes of concrete debris from destroyed buildings in Gaza due to Israeli bombardment, resulting in roughly 37 thousand tonnes of CO2e.

We use carbon emissions of T-walls as a starting point to understand the massive US military carbon footprint during wartime. Specifically, we highlight the importance of examining whole supply chain emissions of T-walls, including "beginning of life" extraction of raw materials,

[3]

and "end of life," or post-consumption, emissions. Our results show that the combined emissions of T-walls used in Iraq came to 54.8 thousand tonnes CO2e which is equal to 12, 782 gasoline-powered US passenger vehicles driven for one year or an average gasoline-powered passenger vehicle driven about 140 million miles in the US. While this is just one sliver of the total carbon emissions by the US military in Iraq, it provides a window into the "hidden emissions" left out of standard carbon measurements.

In the next section we provide a brief conceptual overview justifying the importance of capturing whole supply chains and why, given their enormous carbon footprint, concrete use by the US military during the Second Iraq War provides an ideal study. We then lay a generic framework and methodology demonstrating how despite the lack of response to our Freedom of Information Act (FOIA) requests for data, we were able to overcome this obstacle to put together a unique dataset while simultaneously providing a step-by-step model to guide further research. We then show the utility of this framework with a case study of concrete to make T-walls in Iraq. We conclude by offering a discussion explaining the applicability of developing a methodology for other, similarly opaque situations that can be applied to estimate carbon emissions, or indeed emissions of any waste or side-product that has climate and/or air and water quality implications, for any commodity.

2. Conceptualising the importance of calculating supply chain carbon emissions from militaries

In early 2022, a series of FOIA requests were submitted to the US government's Army Corps of Engineers for data concerning the supply chain of concrete procurement, production, and subsequent carbon emissions in the second Iraq War (2008-2011).[4] After almost a year of many unanswered emails to a number of different US agencies, we finally received a one-line response: "*The U.S. Army Corps of Engineers has no records responsive to your FOIA request*."[5] This response was not very surprising, as anyone who has submitted FOIA request can attest, the process of requesting data from US government agencies, and in particular those which work with military procurement, can be excruciatingly daunting, and at times, downright defeating (Belcher and Martin, 2013). Even during peacetime, military procurement data are usually held over multiple agencies, and procurement of material are sourced across diverse

[4] The genesis of this paper comes from our own experience researching the US Military's carbon emissions under the UK Research and Innovation - Economic Social Research Council project: Concrete Impacts (https://www.concreteimpacts.org/). Grant Ref: ES/V016296/1.
[5] Letter response Army Core of Engineers (10/01/2023)

and complex supply networks, making it difficult to acquire comprehensive datasets. In early days of the Second Iraq War, military procurement was particularly patchy. Poor and missing records of procurement during the early days of US occupation added to gaps in data needed for any meaningful emissions analysis.

We **first,** conducted a comprehensive search of online databases of specifications, e.g., dimensions, weights, values, and materials of military hardware, specifically focusing on T-walls. **Second**, we did comparisons between regional emissions reporting and military standard (usually, International Organisation for Standardization or ISO) to determine a best estimate of what a given factory might emit in each location. **Third**, we used site visits data collected along the chain of supply, **and last**, compared these data alongside ethnographic research in communities downwind and downstream of production to 'ground-truth' environmental impacts.[6] Together, these methods provide data that is surprisingly precise and detailed. We believe this framework can by useful for others to use in situations where emissions data are difficult to acquire due to supply chain complexity, or when data are purposefully held back under the guise of national security during military conflict - providing a generalised model to identify and quantify emission sources in some of the most complex and protracted military supply chains in the world.

We define supply chains as a network of systems that extract raw materials, transform them into intermediate goods and finished products, distribute them to consumers, and manage the waste (Gibbon and Ponte 2005; Gereffi et al 2005; Gereffi and Korzeniewicz 1993). Yet, the definition of what exactly is included and excluded in global supply chain studies is not straightforward (Baglioni et al 2022). For instance, Christopher (1992) defines a supply chain as the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer. Yet, in our mind, these standards "economic-centred" conceptualisations of supply chains, can hide more than they reveal, particularly when it comes to extractive based production systems and the environmental and climate externalities (Neimark et al. 2019; Bair and Werner 2011; Bair 2009). For some, supply chains are an indispensable tool for making meaningful greenhouse gas assessments and reduction targets

[6] There are significant practicalities that need consideration when planning on ethnographic data collection as suggested here. These include access to sites, language, and personal safety. Most importantly, there are key ethical and political concerns like interlocutors' safety, relationships with powerful local corporate and state actors, and control over collected data.

(Coe and Gibson 2023). In their landmark study, Belcher et al. (2020) demonstrate that it is essential to see the much broader scope of supply chains as mandatory tool to conduct comprehensive carbon assessments. Such critical linkages between supply chains and carbon assessments have also been explored to different degrees by Onat and Kucukvar (2020) and Lee (2012).

Often, several independent actors play distinct roles in the chain, including product designers, raw material and component producers, constructors or product assemblers, wholesalers, retailers, transport operators, and consumers (Mentzer et al 2001). Yet, surprisingly enough, while each of these have direct implications for the material and energy required, and hence the size of the total carbon footprint, few standard carbon models tend to incorporate them. Rather, often many of these actors that operate both in the extraction of the raw materials (beginning of life) and/or post-consumption (end-of-life), are either left out, or grossly underestimated (Min and Zhou 2002; Mentzer et al 2001; Stevens 1989). A much broader conceptualisation of supply chains translates to more accurate and comprehensive assessment of an institution's carbon footprint. Afterall, the points of origin and disposal of these components add a significant carbon cost usually left out of most emissions reporting (Berners-Lee 2020; Parkinson and Cottrell 2021).

We understand that a full tracking of carbon emissions from global supply chains is a wicked problem for climate researchers (Meng et al. 2018; Davis et al 2011). Supply chains are unwieldy, complex, and the data needed to conduct LCA are sometimes less than forthcoming (Berners-Lee 2020). When data are available, they are usually inexact or purposefully withheld, deemed too "sensitive" to report under the guise of national security or because of their proprietary nature (e.g., theft of intellectual property). While required by Defense Production Act of 1950 (Public Law 81-774) to keep records on basic materials purchased during wartime operations, the US military rapidly sourced raw materials for concrete production, such as the ingredients of concrete —sand/aggregate, limestone (which is pulverised and cooked into cement) — in the early days of occupying Iraq, without such records.[7] Many of these materials were purchased in haste via local contractors during the haphazard planning of military occupation and therefore with less stringent bookkeeping than is demanded of regular military suppliers. For instance, in Iraq at the time of early occupation, the unanticipated ubiquity of

[7] Defense Production Act (1950, Pub L No. 81–774), Accessed: https://uslaw.link/citation/us-law/public/81/774 (04 March 2024).

IEDs and the effort to secure 5000 US military personnel in central Bagdad's so-called "Green Zone" spurred the rapid procurement of thousands of T-walls (Diamond 2007; Langewiesche 2004). The US military therefore turned to regional contractors, like the Turkish company, 77 Cement, which operated mainly in the Northern Iraqi region of Kurdistan to keep up with demand and keep production generally out of sight of opposing forces (Rubaii 2022). It is important to note that because T-walls did not exist before the US invasion, these military contracts also served as foundational for small concrete-industry companies to build multinational partnerships that accelerated the net production and consumption of concrete in Iraq, often under regulatory exception in the name of post-war reconstruction. In Iraq, this complex military supply chain ultimately bled into the concrete supply chain more broadly. We note these radiating economic impacts of military enterprise on concrete supply chains in general (and therefore increase in overall emissions from concrete production), but we limit the scope of our analysis to T-walls procured by and for the US military.

These "hidden" production costs within military enterprise, and their corresponding carbon emissions, add up. The US military is estimated to be one of the biggest single institutional carbon polluters ever, supported by emerging independent studies of military emissions (Crawford 2021; Belcher et al 2020; Parkinson and Cottrell 2021). Analysis of full supply chains from raw materials to post-consumption is less forthcoming. Recent estimates show that the US Department of Defense (DOD) released 55.4 million metric tonnes of CO_2eq in 2018, roughly equivalent to the emissions of 12 million standard cars (Crawford 2021). If the US DOD was a country, it would be the 54th highest emitter globally (Belcher et al 2020). However, the US military has long been exempted from reporting their greenhouse gas emissions, and therefore there remains significant gaps in our understanding of their full carbon footprint (Rajaeifar et al. 2022).[8]

By focusing on the production of T-walls from concrete, we hope to provide researchers with a way forward by providing a framework to stimulate methodologies which can begin to accounting for supply chain emissions produced by the US military, as well other large institutions and organisations. In the absence of accurate reporting, the setting of meaningful reduction targets, not just for the institution or sector itself but globally, becomes impossible. Our aim, therefore, is to demonstrate that such accounting can be done, and reveal why it must be done. We do this by analysing the carbon output of the supply of military-grade concrete in

[8] During the 1997 Kyoto Protocol negotiations, US delegates lobbied on the grounds of national security to exclude the military from reporting requirements for greenhouse gases.

an active theatre of war to demonstrate for others how to break down one component of the very complex and large US military procurement supply chain.

3. A framework for assessing complex supply chain emissions

Simply put, the carbon footprint is the sum of the emissions that derive from activities at all stages of its supply chains (Sundarakani et al. 2010). For supply chains involving producers that transcend international boundaries, accounting for the carbon embodied —basically the carbon bound up in the making of its parts —requires systematic scrutiny at each stage of the process (Peters 2010). As depicted in Figure 1, we begin by identifying and demonstrating specific indicators for the required measures at each stage of the processes as they pass through the different Tiers of procurement and extraction all the way to the end of the lifecycle. The production of consumables depends on inputs of both material and energy inputs as well as product distribution, consumption, and disposal of what may be left over. Hence, the emissions associated with each Tier of suppliers needs to be included in the inventory. For instance, direct supplier, e.g. Tier 1, those subcontracted to fill orders for direct suppliers, and Tier 3 who help supply those Tier 2 subcontractors (see Wilhelm et al. 2016; Schmidt 2009).

Figure 1 Schematic Diagram of a Generic Supply Chain

3.1 Defining the goal and scope of LCA - Step 1

It is important to define fully the system boundary when computing the carbon footprint. System boundaries are clear definitions of the product's life cycle that will be included in the assessment (Li et al. 2014). This is necessary as the life cycle of a product are often numerous and can be difficult, if not impossible, to collect data that covers all processes. The goal of the LCA determines the approach used and the impact measures.

We have segmented the life cycle of a supply chain into the management of input materials and the management of the final product to simplify the systematic itemisation of entries required for the life cycle inventory. The assessment covers the full life cycle of concrete walls-from cradle to grave. Input materials for the production company under consideration can be classified as Tier 1 (primary suppliers) and Tier 2 (secondary and often sub-contracted suppliers who mainly supply raw materials). It is important to be alert to multiple tiers in very complex supply chains (e.g., in our analysis we have both Tiers 1 and 2 suppliers of input materials). Also, the goal of this framework is to demonstrate how to compute the amount of carbon embedded in military supply chains and the potential contribution to climate change. Hence, we use a midpoint indicator of Global Warming Potential of GHGs measured as carbon dioxide equivalent (CO_2e), as an indication of the amount of carbon embodied in military supply chains.

3.2 Inventory analysis of raw material acquisition - Step 2

Carbon emissions from the acquisition of raw materials consists of both stationary and mobile combustion of fuel in equipment such as excavators and diggers and vehicles that extract, crush, and move raw materials to the production plant. Combustion emissions from mobile sources are computed either using the quantity of fuel consumed and an emission factor associated with the type of vehicle and conditions of its use (WRI 2015) or, when data on fuel use are not available (IPCC 2006), the mass of material produced and a typical emission factor for the fuel used for that activity (ICE 2019). The choice of approach depends primarily on the purpose of the calculation and secondly the "type" of data available. Whereas the fuel-based method is more precise and is suitable for real-time monitoring of emissions based on amount and type of fuel, the product-based method is appropriate for comparing efficiency of production methods and facilities (IPCC 2006). For stationary combustion sources, data on energy source (e.g., coal, natural gas), energy usage (e.g., kWh of electricity) per kg of raw material (for an energy use approach) or quantity of raw materials produced (for a material used approach), and emission factors for the specific energy source. Emissions is then computed as a product of the quantity of fuel and the emission factor.

Our calculations are as follows:

Emission is then computed as: GHG Emissions from fuel = Fuel Consumption (F) * Emission Factor GHG (E) …………. **Equation 1**

Where multiple sources of fuel are used, the total emissions are computed as an aggregate:

Total GHG emissions $= \sum_i FiEi$……… **Equation 2**

where Fi is the fuel type and Ei the associated emission factor.

For this model, we use the mass of material approach due to lack of data on fuel use (see section on methods). The limitation is that emission factors can vary between production facilities and methods. We use emission factors that reflect the production method in Iraq to minimise this limitation.

3.2.2 Inventory of production - Step 3

The potential sources of direct and indirect GHG emissions at the production facility include direct process emissions from combustion of fossil fuels, on-site energy production (stationary combustion), mobile combustion sources owned or controlled by the reporting company, and waste disposal in landfills. Electricity and other sources of energy that do not involve on-site combustion, such as steam, and chilled or hot water purchased from a local utility are often categorised as Scope 2 emissions for the reporting organisations and are included as such at this stage in our assessment. Utilities combust fossil fuels such as coal and natural gas to generate energy emitting carbon dioxide, methane, and nitrous oxide in the process (WRI 2015). We also account for vehicles used onsite for moving material and finished products between units or to delivery trucks in our calculation of production site emissions.

Activity data for computing emissions are based on fuel combusted or quantity of final product. The amount of GHGs emitted is a product of activity data and industry-specific emission factors (See Equations 1 and 2 above). Supply chains typically involve multiple producers; hence each should be systematically accounted for in the inventory. If the reporting organisation use products imported from other producers as inputs for their own production, the upstream production chain of these should also be systematically included, with the carbon embodied in that product again considered from cradle to the point of inclusion. It is essential that the boundaries of the assessment are clearly defined.

3.2.3 Inventory of distribution - Step 4

Emissions from distribution infrastructure incorporates those from depots, warehouses, stores, and vehicles. These include emissions from static and mobile emissions, such as cranes and mechanised forklifts for loading and unloading supplies, as well as heating, air conditioning and lighting (Fichtinger et al. 2015). The distribution of military supplies is potentially complex as they involve multiple types of vehicles which consume using different types of fuel, each with their own carbon emissions factors (e.g., diesel vs. jet fuel) (Belcher et al, 2020). A comprehensive assessment requires disaggregating the distribution process into the modes and stages of transport and fuel used for each (ECTA-Cefic 2011). This can begin with identifying the source of product and the initial destination, to enable the calculation of distance travelled. Then identifying the mode of transport and the type of vehicle used are all useful for the selection of suitable emission factors.

3.2.4 Inventory at point of use - Step 5

The type of activities and equipment at the point where the product is used by the consumer influences the amount of carbon the product embodies. Emissions at the "point of use" (i.e. where the product reaches the consumer) include fuel for unloading products and for erecting structures, and direct emissions from use of the product. In the case of this study, point of use begins when a T-wall is finished and changes hands between the distributer and the end user – in this case, the emplacement of the wall segment. The building industry, the embodied carbon (comprising of emissions from manufacturing, transportation, installation, maintenance, and disposal) are accounted differently from the operational carbon which are emissions from building energy use such as for heating and cooling (World Green Building Council 2019). End-of-life management includes emissions resulting from demolition, movement of debris, and potentially carbon capture. Sources of carbon emission include fuel combusted to unload goods, energy used for preservation, and quantity and type of waste disposed. For construction materials, the fuel used in erecting structures, gathering and disposing of debris, as well as emissions from the operational lifecycle of the product such as heating houses are counted. Emissions are computed by multiplying the material consumed or disposed by an item-specific emission factor. This can be done using the UNFCCC GHG emission calculator if emission factors are not available for the specific situation.[9]

Decaying organic matter at landfill sites releases the carbon it embodies directly into the atmosphere, or to the soil from which it is released in the form of carbon dioxide or methane into the atmosphere. Using wastes as fuel sources can result in less carbon-intensive production, which must be accounted for in the assessment of production emissions. Furthermore, cement-based products slowly reabsorb atmospheric CO_2 through a physiochemical process called carbonation when CO_2 diffuses into the pores of hydrated cement material. This slow process takes many years throughout the entire life cycle of cement-based materials and could result in as much as 43% sequestration of CO_2 emissions from the production of cement (Xi et al 2016). We do not include this in our analysis due to data deficits and uncertainty.

3.3 Impact assessment - Step 6

Life cycle impact assessment is aimed at quantifying and evaluating the magnitude of the environmental impacts of the product or service being studied. Impacts can be quantified using

[9] UNFCCC, 2011. Greenhouse Gas Calculator (2021), accessed at: https://unfccc.int/documents/271269 (08/17/2023).

midpoint and endpoint indicators. Midpoint indicators are intermediate measures of environmental impact caused by resource use or carbon emissions. These include climate change or global warming potential (GWP), human toxicity, land and water depletion. GWP is a common midpoint impact category which measures the potential climate impact of greenhouse gases over a period relative to carbon dioxide and is expressed as carbon dioxide equivalent (CO2e) (Guinée 2002). Thus, CO_2 is the reference gas and has a GWP of 1. Radiative Forcing (RF) is another measure of climate change, albeit less frequently used in LCA. RF measures the changes in energy balance in the atmosphere due to GHGs (IPCC 2021). Midpoint indicators are easy to calculate as they are closely related to inventory data and are less affected by uncertainties and assumptions. End point indicators on the other hand are more comprehensive, as they measure ultimate impacts of emissions on human health, ecosystem quality, and natural resources. Years of life lost is a commonly used endpoint indicator for the impact climate change on humans (Huang et al 2012; Knowlton et al 2011). End point indicators use long-term modelling approaches and incorporates relevant wider social and environmental factors; hence they are less accurate and have higher levels of uncertainty (Huijbregts et al 2017; Steinmann et al 2016). We use the carbon dioxide equivalent as an environmental impact measure (Heijungs et al 2003). There are several tools for conducting impact assessment, and these include SimaPro, LINA, One Click LCA and Open LCA. In this assessment, we applied the characterisation factor derived from the Inventory for Carbon and Energy (ICE) database and the GHG Emission Protocol to activity data to compute the CO2e for material and processes in the supply chain.

3.3.2 Estimation of uncertainty

Uncertainties in the estimation of emissions arise from lack of resolution and specificity of activity data and emission factors. It is imperative therefore to itemise all activity data and emission factors and the uncertainty associated with each for all materials and activities over the product life cycle (WRI 2011). The level of uncertainty can be derived from an assessment of the data quality using data attributes such as temporal and geographic coverage (IPCC 2006). The contribution of each uncertainty to the overall result can thus be computed. From here, there are several methods available for computing total uncertainties. We follow the template of the GHG protocol[10] developed by the World Resources Institute (WRI) and the World

[10] WRI/WBCSD, 2011. Greenhouse gas protocol, accessed at: https://ghgprotocol.org/calculation-tools (08/17/2023).

Business Council for Sustainable Development (WRI 2011), which uses a first order error propagation method in a Monte Carlo simulation (see Neimark et al. 2024).

4. Carbon emissions of T-wall supply chains[11]

In order to apply these methods to T-wall production in Iraq, within the timeframe of post 2003 US invasion and 2008, we first conducted a comprehensive search of online databases of specifications, e.g., dimensions, weights, values, and materials of military hardware for T-walls. We then did comparisons between regional emissions reporting and International Organisation for Standardization (ISO) to determine a best estimate of what a given factory might emit in each location, using one sample company: Iberia Concrete. We also used site visits data collected along the chain of supply to identify less-documented production processes. Finally, we compared these data alongside interview data in communities on their experiences with the environmental impacts of T-Wall production.

4.1. Wartime emissions of concrete T-walls

Our comprehensive search of online databases of specifications, e.g., dimensions, weights, values, and materials of military hardware for T-walls included historical context for changing production and specifications on the materials utilized. Concrete T-walls were introduced into Iraq by the US military and allied forces during the invasion in 2003 and have since become an integral part of warfare and security beyond the US military to include consumers such as embassies, banks, and municipal compounds (Rubaii 2022). The concrete wall-building industry was one of the biggest industries in Iraq during the height of the kinetic violence in 2006-7 (Bernsen 2008), far out-stripping local supply capacity. T-walls used in Baghdad were therefore sourced from Iraqi Kurdistan and even imported from neighbouring countries such as Turkey and Kuwait (Matten 2008; Finoki 2006).

The US military's demand for T-walls required rapid installation. For example, the 1st Armoured Division Engineer Brigade placed roughly 15,000 T-wall units at military camps during the Second Iraq War (McEntee 2004). Meanwhile, the infamous 5km and 4.6 km long Great Wall of Adhamiya and Gold Wall of Sadr City, respectively, each measuring 3.7m in height, give an indication of the extent of concrete used in Baghdad (Johnson et al. 2008; Spencer 2019). In addition to grave long-term social impacts of these walls on Iraqi civil

[11] This section consists of the outputs of applying the steps outlined in section 3. It does not align directly to the steps outlined but provides a clear picture of the results when applied methodology is used.

society, including contributing to sectarian cleansing (Rubaii 2019) these walls also generated major privatized profits. One US logistics officer disclosed procuring US$41 million worth of barriers for a single unit (Finoki 2008). The exact quantity of T-walls laid during this period is unknown as many individual units, civilian companies and agencies contracted from different suppliers separately (McEntee 2004). Such was the lucrative nature of this new industry that existing suppliers, such as the "77 Group," restructured to focused exclusively on concrete blast wall delivery, earning the group the moniker "the blast wall haulers." T-wall factory managers interviewed by Rubaii in 2021 explained that the cost of production for T-walls is about $200 a piece, but the price per unit paid by US military contracts was much higher, sometimes generating a profit of 7xs the price of production.

Initially, this mark up in price was due to limited competition. As more and more competition developed, the sale-prices were driven down and the production costs remained the same, or sometimes went up with local raw materials ran low. Rubaii's site visits with managers at four different T-wall companies were weighted with secrecy, primarily out of a concern by the managers about the theft of blast-grade concrete recipes and the increasing number of competitors. A long-time manager at 77 Group in Erbil told Rubaii: "*We used to be the only ones making T-walls. We had the formula, the contracts. Then, the secrets got out and we had new competitors. So, we are very careful who we hire now*."

However, most companies have since diversified their production to include other moulded concrete products for roadways, water drainage, and walls. The procurement process can be described as complex and secretive, involving global contractors, such as Kellogg Brown and Root (KBR) and sub-contractors who were both local and foreign companies (Klein 2007). This complexity and the veil of secrecy emanate from the privatisation of war —what has been termed "disaster-capitalism complex," where conflict and disaster-related operations such as securing borders, waging war, and rebuilding cities are performed by third party companies for profit (Swed and Crosbie 2011; Klein 2007). This means that the military does not in fact have a full oversight of Tier 2 supply chain activities, for example, how much raw materials (e.g., sand and stones) were extracted to produce the concrete.

Today, T-walls are used by a range of security actors, including military and police forces in Iraq. T-walls function to sequester wealthy and ruling class communities in the Green Zone, or to garrison public spaces and shut down popular protest in places like Tahrir circle. Their functional role in limiting the scope of democratic governance directly contributes to limitations of popular organizers to push for environmental regulations on extractive industries in Iraq more broadly. Factories and raw materials mining companies can and do circumvent existing paltry environment and labour regulations through corruption schemes.

We address a major data and methodological gap using a novel hybrid-bottom-up life cycle analysis approach. Our approach leverages the strengths of a process-based LCA, by adopting an itemised estimation of the carbon emission at all stages of the product's life cycle, while also mobilising the comprehensiveness of an input-output approach (Zhu et al. 2023; Kennelly, et al. 2019). We achieve this by capturing both process-based and material flow emissions from "cradle to grave," including pre-, and post-lifecycle analysis of a single T-wall.

Using this approach, we identify and map the key nodes of the military supply chain for T-walls, *viz.* the location of the concrete production plant and source of raw materials, and potential points of use. We therefore home in on one concrete production company, Iberia Concrete, as an exemplary case study. Due to the lack of broad data, we assess the amount of carbon embodied in a single T-wall from cradle to crave and then extrapolated to the total number of walls (see Neimark et al. 2024). We estimate the process-based and material-flow carbon emissions from field data and grey literature and then extrapolate outward to compute total carbon emissions from the total individual T-walls over a given period. In this case, because our focus is specific to US military carbon emissions, we will calculate the total T-walls commissioned by the US military between 2003 and 2008. Given the long-dure decomposition of T-walls, this means the "end date" is marked by the end of commissioned production dates, while the total life cycle emissions calculations will project into the future.

4.2 Inventory analysis for the supply chain of concrete T-walls

We then compared regional emissions and ISO reporting to determine a best estimate of what a given factory might emit in each location, using one sample company. Iberia Concrete has been operating in the Kurdish region of Northern Iraq for the past 20 plus years. The company produces concrete security barriers used to protect military bases, government buildings, airports, schools and stadiums from potential terrorist attacks and vehicular accidents. The company produced concrete sections of T-walls from 5000psi (35MPa) concrete reinforced with steel (Iberia 2015). The company conducts both extraction of raw aggregate such as sand and stones, and procures secondary inputs such as cement and steel, thereby fulfils both the Tier 2 and Tier 1 supply roles (Iberia 2015). Figure 2 shows the supply chain for T-wall sections produced at Iberia's Erbil production facilities and transported to Baghdad.

We have divided the sources of carbon emission considered in this case study into five major categories: (i) extraction and processing of raw materials, including Tier 2 (sand, gravel/stones/aggregates and blasting), and Tier 1 (cement and steel) suppliers, (ii) concrete production, (iii) placement and removal of T-walls from site, (iv) temporary storage, and (v) transportation at all stages (Figure 2). Tier 1 suppliers are companies that supply input materials directly to manufacturers or product assemblers, while Tier 2 suppliers provide raw products to Tier 1 suppliers.

Figure 2. Stages of the Iberia Construction concrete T-wall supply chain

Tier 2 included the inputs of raw materials[12]

This category includes the aggregates (sand and stones) for the concrete were extracted from the Zab River which is about 50 km northwest of the factory (See Figure 3), which are transported from the quarry to the production facility using heavy duty trucks of average size of 20 tonnes. Water was extracted from a borehole drilled at Iberia's premises, tapping into an underground freshwater aquifer, identified as one of Iraq's main long-term sources of water for drinking and crop irrigation. The effects on freshwater ecosystems in Iraq's riverbeds is also shaped by aggregate mining, a process through which pebbles and sand from the river bottoms is dredged for concrete production, destroying habitat for egg-layers including those fish that sustain fishing communities in Iraq. While water use has major environmental impacts, emissions from the extraction of water is negligible, hence we do not include it in this analysis (Kua et al. 2014).

Tier 1 inputs of cement and steel

It has been reported that concrete production companies import cement and steel from Turkey, Iran and other countries (Finoki 2008; Klein 2006), but, for this case study, we focus on cement sourced from a local supplier (Mass, Kar Group) and steel from the Erbil Steel Company (see Figure 3 for a map showing the steel and cement production sites relative to the Iberia Concrete factory). We use existing estimates on the amount of carbon embodied in 1kg of cement and steel from the Inventory for Carbon and Energy (ICE) since data on downstream production is not available.

[12] Tier 2 and 3 suppliers are those closest to the raw or source material, whereas Tier 1 is linked to the final product. This is why we begin with Tier 2 and move to Tier 1 inputs – see figure 1.

Doing an LCA of T-wall production does not only supports a broader analysis of military emissions – it also offers an indication of related production cycles linked to war but unaffiliated with military consumers. For example, Iraq has faced several waves of urban destruction from warfare that multiplies the net demand for concrete. Atef, a manager at one of the cement factories in Bazian Valley, did the math out loud in an interview: "It is undeniable that war creates a demand… If a wall should last 50 years, but… then it was destroyed after just 2 years, that means it is 50 minus 48 years. That is 48 years lost for the wall. That increases demand very fast. Our speed is accelerated by many times." Urban destruction also induced a spinoff economy: that is the circulation of scrap metal, which is melted into low-quality rebar, often in the same place as cement extraction. The emissions from this "second life" of steel are not included in our calculations, though this second metabolization of metals would certainly add to total emissions in the "disposal" stage.

Figure 3: Map of Iraq showing the location of raw materials, concrete batching plant, locations where T-walls were emplaced, and storage locations after removal from site.

To estimate the amount of carbon embedded in the supply chain, we use the proportion of cement, sand, crushed stones and water used for a concrete slab with 35MPa compressive strength (M35) specified by the 2007 Portland cement Association report (Marceau et al. 2007). A standard T-wall produced by Iberia Concrete Company is typically 1.5 m long and 3.65 m high, 2.24 m^3 in volume, and weighed 5500 kg (Iberia Construction 2015). We use the ICE specification and assume a steel content of 100 kg per cubic metre of concrete (ICE 2019), with emission factors also taken from ICE. Hence, we assign 1% uncertainty in the data quality of the constituents of concrete and 10% for emission factors (IPCC 2006). We compute the amount of carbon embodied in raw materials used for making a single T-wall section as a product of the quantity of materials and the corresponding emission factors. The cumulative uncertainty is computed using the GHG Protocol[13]. The extraction of raw materials for single concrete T-wall contributed 1063.4 $kgCO_2e$ of carbon (Table 1).

Table 1: Emissions from raw materials extraction for producing a single T-wall

Constituents	*Quantity per m^3 of concrete (kg)*	*Quantity per T-wall (kg)*	*Emission factor ($kgCO_2e/kg$)*	*Total emissions (kgCO2e)*
Water	141	315.84	0.000344	0.11

[13] Greenhouse gas protocol 2024. Accessed at: https://ghgprotocol.org/calculation-tools-and-guidance (12/01/2024).

Sand	712	1594.88	0.00747	11.91
Stones	1187	2658.88	0.00747	19.86
Cement	335	750.4	0.912	684.36
Steel	100	224	1.55	347.20
Total				**1063.4 $\pm$ 8.1%**

Source: Computed using standard activity data for a 35MPa concrete from PCA, 2007 and emission factors from ICE 2019

Concrete is produced from cement, aggregates consisting of sand and crushed stones, and water of which cement is the main source of carbon (Neimark et al., 2024). The production of cement releases CO_2 both directly from the heating of limestone and indirectly from the combustion kiln fuels such as coal, fuel oil and natural gas (Habert et al., 2020; Hanley et al., 2004). The raw meal consisting of crushed limestone and clay is heated in the kiln to 1,450°C to produce clinker. In the process called calcination, large amount of CO_2 is emitted from the decomposition of limestone (which is made of calcium carbonate) to lime (See Equation 3).

$CaCO3 + Heat \rightarrow CaO + CO2$.......... **Equation 3**

Thus, about half of the CO_2 embodied in cement is from the calcination process (Ostovari et al. 2021; Huntzinger and Eatmon 2009; Marceau 2007). The amount of carbon embodied in cement is dependent on the proportion of clinker, which is the main constituent (about 95%) of the Ordinary Portland cement, the predominant cement consumed globally today. The amount of carbon that clinker embodies may vary depending on the production technology, and the type of kiln fuels, and the energy sources used in electricity generation (CSI-GNR 2019; Gursel et al. 2014). In addition, cementitious materials such as slag, fly ash and silica fume are sometimes used as replacement for a proportion of cement in concrete to reduce the embodied carbon as cement is the main source of GHG emissions (Ahmad et al., 2021; Liew et al., 2021). Our analysis considers CEM 1- Ordinary Portland Cement with no cementitious materials to produce T-walls, as this is the main type of cement produced in Iraq (Szczesniak, 2021; Cement Sustainability Initiative, 2019). The constituent mix of CEM I is 94% clinker, 5% gypsum, and 1% minor additional constituents (BS EN 197).

T-walls are reinforced with “rebar” (or reenforcing steel bars used to strengthen concrete under significant tension) - adding another major source of carbon as the production of steel is even more carbon intensive than cement. On average every tonne of steel produced in 2020 led to the emission of 1.851 tonnes of CO2 (World Steel Association 2021) while the ratio of the tonnes of cement produced to the associated carbon emitted is about 1:1 (Fisch-Romito 2021;

Monteiro et al. 2016). The constituent mix of concrete depends on the required compressive strength (Marceau et al. 2007), which for blast walls is stipulated as 35 MPa. Different mixes of constituents produce M35, and each is associated with different magnitude and composition of emissions (Miller and Moore, 2020). It should be noted that admixtures such as superplasticizers, air entraining and accelerators are widely added to concrete to enhance its properties (Gursel et al. 2014). However, since they constitute less than 1% of the mass of concrete and thus produce negligible emissions (Marceau et al. 2007), they are not included in this analysis.

4.3 Extraction of raw materials and local impacts

We also used site visits data collected along the chain of supply to identify less-documented production processes.

At the site of cement extraction, where limestone is converted to cement before it is purchase by companies like 77, the ecological impacts are extreme. For example, in Bazian Valley in northern Iraq, nicknamed Cement Valley for its many cement factories, dynamite is used to blast the sides of limestone hills, while large trucks collect and carve the stone down to nearby factories where these stone pieces are cooked at high heat into clinker. Clinker is crushed into powder, leaving a thick haze of fine particulate matter sitting in the air. This entire process not only emits carbon, namely in the heating and cooling process; it also changes the topography (flattening hills) and reduces ground cover (like trees), thereby contributing to increasing sandstorms, air pollution, and regional heating. Farmers in the valley complain of a reduction in the water supply, as factories use more and more for concrete and leave less for irrigation. Air pollution, and water contamination, and noise pollution were the top three complaints among communities living near cement production in northern Iraq when Rubaii conducted an environmental health survey in 2021 and 2022.

Rubaii also visited cement quarries and factories nearby. Some managers referred to policies drafted in the early 2000s that deregulated extractive industries and incentivized rapid extraction without environmental or labour protections as an explanation for the extreme air pollution surrounding their quarries and factories, while others mentioned warfighting as major accelerants to their rapid extraction of limestone. Azad (pseudonym), an engineer at a LaFarge cement quarry told Rubaii, "*We cut the mountain into these disposable cubes. My income is in opposition to my air quality… This is a war mentality, to completely destroy a place. It comes directly from the deregulation policies that the Americans introduced*."

Notably, these factories mostly employ imported labour from Indian and China, which is cheaper than local labour. This means that local community members, driven out by pollution from the factories and reduction in their farming capacity near factory production, are not getting jobs at the factories. They are moving into urban centres, increasing their own net concrete consumption. Meanwhile, "guest" workers have limited recourse for their working conditions. While not often included in LCA calculations, and not calculated here, transcontinental transportation of workers is a contributing factor to the total emissions of this industry.

4.4 Emissions at production, transport, and removal sites

We compared quantitative data with ethnographic research in communities downwind and downstream of production to 'ground-truth' environmental impacts, including emissions at sites of production, transport, and emplacement/removal.

Emissions at the Production Plant

The production of concrete involves two key stages, batching and casting. The term "batching" refers to the mixing of raw materials, aggregate (i.e. sand, pebbles, and crushed stones), cement, and water in predetermined proportions to produce concrete that meets the mechanical requirements. The concrete is then cast in moulds to produce each T-wall that weighs 5500kg (Iberia Construction 2015). Emission factors per kilogram of precast concrete have been obtained from the ICE. The total carbon emission for each process is computed as:

*Carbon = (Quantity of concrete in kg) x (Emission factor in kgCO2e/kg)……..***Equation 4**

We obtained the mass of concrete T-wall from the production company; hence we assign an uncertainty of 1%. We again assume an uncertainty of 10% for emission factors as they are non-case-specific (IPCC 2006). The emissions at the production site associated with a single T-wall is 81.95 kgCO2e (Table 2).

Table 2: Carbon emission at the production plant

Process	*Quantity of concrete (kg)*	*Emissions per kg concrete (kgCO2e/kg)*	*Total emissions (kgCO2e)*
Batching	5500	0.0007	3.85
Casting	5500	0.0142	78.10
Total			**81.95 + 9.6%**

While the local environmental burdens at batching plants appear minimal compared to sites of cement extraction, the impact of aggregate mining in tributaries to the Tigris and Euphrates have severely damaged local the river ecologies. When aggregate sand and crushed stones that are brought to batching plants to be mixed with cement and water, they are often trucked from riverbeds. The process of dragging the river bottom to the surface with machinery not only destroys habitats where fish and other aquatic species lay eggs, it also changes the flow of the rivers. The long-term impact of flow change is to produce pockets of bacterial overgrowth, eutrophication, and other imbalances that make the river ecology unstable. Iraq is a country that relies on its twin rivers and their tributaries. Under-regulated aggregate mining is of increasing concern to environmentalists and river-dependent communities downstream.

Transport-based emissions

Transport-related emissions can be computed using an activity-based or energy-based approach (IPCC 2006; McKinnon and Piecyk 2010). Here, we use the activity-based approach due to lack of available data on fuel consumption for the vehicles used. Emissions are thus computed as:

GHG emissions = (Tonnes of goods transported) x (average distance travelled in km) x (emission factor per tonne-km for the vehicle type). ………….. **Equation 5**

We use the GHG Protocol's Transport tool for estimating transport-related emissions (WRI 2015). The tool uses emission factors from the UK Department for Environment, Food and Rural Affairs (DEFRA), the US Environmental Protection Agency (EPA) and the Intergovernmental Panel on Climate Change's (IPCC). We assign the maximum IPCC recommended uncertainty of 10% to these emission factors. Blast walls are transported by road using Heavy Goods Vehicles (HGV), typically a 40-foot trailer with engine size of about 40 tonnes (Matten, 2008). Distance travelled is estimated using OpenStreetMap. The location of raw materials were identified using a participatory Geographic Information System (PGIS) approach with a key informant (Brown et al. 2014). Figure 3 shows the location and flow of material along the supply chain. We assume a maximum truck payload for outward trips and empty (zero payload) truck for return trips. This conforms to the IPCC's mobile combustion estimation which factors fuel type, vehicle type, and road conditions (IPCC 2006). The relationship between payload and GHG emissions is not linear (McKinnon and Piecyk 2010; ECTA-Cefic 2011), hence emissions from the empty return trip is not necessarily lower than the outward trip with load (see Table 3).

Table 3: Emissions from transporting a single T-wall and its raw materials and along the supply chain

		Material transported for trip with load		**GHG (kgCO2e/tonne-km)**		
Constituents	*Distance (km)*	*Weight (tonne)*	*Tonne-km*	*Trip with load*	*Empty return trip*	*Total*
Input materials						
Water	0*	0.32	0.00	0.00	0.00	0.00
Sand	44.1	1.59	140.67	14.30	0.90	15.20
Stones	58.2	2.66	309.49	31.58	1.19	32.77
Cement	73.4	0.75	115.11	11.23	1.50	12.73
Steel	28.2	0.22	12.63	1.27	0.58	1.84
Factory to site						
Green Zone (GZ)	377	5.50	4147.00	422.96	7.69	430.65
Gold Wall (GW)	366	5.50	4026.00	410.62	7.47	418.09
Site to graveyard						
GZ to Fadhil	16	5.50	176.00	17.95	0.33	18.28
GW to Al-Sadda	4.1	5.50	45.10	4.60	0.08	4.68

*Water is extracted at the site of production, hence transport-based emissions are not applicable

So far, we have presented the carbon embodied in the stages of the supply chain for the production, transport and use of a single T-wall. A single T-wall produced in Erbil in Northern Iraq, transported to Baghdad for fencing the military-controlled Green Zone, and removed and temporarily stored at Fadhil in southern Baghdad produces 1602 kgCO2e of emissions. The same product which is transported to Sadr City to construct the Gold Wall, and subsequently stored at Al-Sadda after use produces 1576 kgCO2e of emissions, which 26 kgCO2e lower than the T-wall on the Erbil-Green Zone-Fadhil route.

Table 4: Total emissions from the stages of the supply chain for a single T-wall

Stage of supply chain	Carbon emissions for a single T-wall (kgCO2e)	
	To the Green Zone	To the Gold Wall
Raw materials	1063.4	1063.4
Production plant	82.0	82.0
Transport	448.9	422.8
Point of use	7.7	7.7
Total	1602.0	1575.9

Total emissions from T-walls used at the Green Zone is 49.2 thousand CO2e while that for walls used at Sadr City for the Gold Wall is 5.6 thousand tonnes CO2e (See supplementary material). The combined emissions of 54.8 thousand tonnes CO2e is equivalent to 12,782 gasoline-powered passenger vehicles driven for one year or an average gasoline-powered passenger vehicle driven about 140 million miles in the US, and its effect is equivalent to carbon sequestered by 54,968 acres of U.S. forests in one year. Of the total emissions, about 77% was due to the production of T-walls (Figure 5). This is mainly from tier 1 input materials such as cement and steel. Emissions from the T-wall production factory (that is batching and casting) contributed only a small fraction of the total amount (Kua and Kamath 2014).

Figure 4: Proportion of carbon emitted at the stages of T-wall supply chain[14]

Figure 5: Supply chain transport emissions at different production nodes

Emissions from emplacement and removal of T walls

T-walls are modular, and their mobility means that, with heavy machinery, they may be moved more than once during their use. However, to remain conservative on emissions estimates, we calculate for only two major trips a T-wall takes: emplacement and removal from a single location. The US Marine Corp used a MAC-50 Crane, a Palletized Loading System, and a Skytrak 10k ATLAS Forklift for collecting, transferring and erecting the T-walls (Hurtado, 2015). Kua and Kamath (2014) notes that the diesel fuel consumption of similar vehicles for loading and unloading concrete is about 0.010 MJ per 1 kg of concrete which we convert to kWh and then compute emissions from loading one T-wall onto a truck as:

Carbon emission = (energy used per kg of concrete in kWh) x (weight of T-wall in kg) x emission factors. ……………….. **Equation 6**

Emission factors are estimated from UK Government GHG conversion factors for primary fuel sources combusted at a site. We assumed fuel consumptions and emissions from loading T-walls at the batching plant and unloading at the place of use to be the same. We assign the maximum uncertainty of 10% associated with emission factors according to IPCC uncertainty guidance (IPCC 2006) and 5% for activity data based on technological and geographical correlation (WRI 2015; Weidema and Wesnaes 1996).

[14] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results

When T-walls have reached the end of their useful life, they undergo three possible end-of-life processes: One, they can wither on site at a checkpoint or as part of a wall, painted repeatedly and sometimes moved back and forth to block roads until they become too broken down to use. In this case, a T-wall may rest on its side or in an empty lot indefinitely. Two, they may be trucked to a "graveyard" along with thousands of other T-walls in a massive field of decommissioned T-walls (see Figure 4). This process was at its height during US withdrawal. Three, T-walls may be pushed into rubble piles along the side of highways along with other waste from demolitions. They may be partially burned along with other materials, waste, and sometimes crushed and dismembered by scrap metal recyclers who work to break down and process demolition waste at an accelerated rate.

We therefore consider those T-walls that were deposited at the "concrete graveyards" in places like Fadhil and Al-Sadda (Bernsen 2008). We assume that removed T-walls are stored at the nearest storage location included in this model: Fadhil for those from the Green Zone, 16 km, and Al-Sadda for T-walls removed from the Gold Wall, 4.1 km (see Figure 4). We compute the carbon emissions from unloading the concrete slabs at the temporary location. We do not include secondary processes associated with the carbon cycle such as the re-absorption of atmospheric carbon during the lengthy decay period due to lack of data. The amount of carbon emitted at the point of use of a T-wall is presented in Table 5.

Table 5: Emissions at the point of use for a single T-wall

Constituents	Energy used/kg (kWh)	Weight of T-wall (kg)	Emission factor (kg CO2e/kWh)	Total GHG (kg CO2e)
Loading to truck	0.0028	5500	0.25	3.87
Unloading at site	0.0028	5500	0.25	3.87
Total				**7.7±7.9%**

So far, we have presented the carbon embodied in the stages of the supply chain for the production, transport and use of a single T-wall (See Table 6 below).[15]

Table 6: Total emissions from the stages of the supply chain for a single T-wall

Stage of supply chain	Carbon emissions for a single T-wall (kgCO2e)	
	To the Green Zone	To the Gold Wall

[15] The total number of t-walls used in Baghdad and associated embodied carbon has been presented elsewhere (see Neimark et al 2024).

Raw materials	1063.4	1063.4
Production plant	82.0	82.0
Transport	448.9	422.8
Point of use	7.7	7.7
Total	1602.0	1575.9

There appears no plan of the potential use of the T-walls beyond their primary purpose for security, segregation, and protection. The first T-walls were taken down in August 2009 as U.S. troops began to withdraw (Rubaii 2022). While Hesco barriers, structures built from sandbags, are easy to dispose of, with the sand mainly re-purposed at nearby golf driving ranges and the barrier frame recycled, many concrete T-walls were removed and dumped *en masse* in ‘concrete graveyards’ (Bernsen, 2008). Large cranes and lifting gear are used to hoist T-walls onto trucks which are conveyed to a temporary storage site. An estimated 18,000 T-walls in Baghdad, including 14,000 in the Green Zone had been removed by 2019 (France24 2019; Arab News 2019), i.e., 45 and 35 km respectively. Nonetheless, T-walls continue to be used in Iraq and continue to be produced. They remain a major feature of Baghdad’s urban landscape and of Iraq’s major regional checkpoints and military installations, with rippling environmental impacts. The afterlife of T-walls, perhaps more than their disposal into “graveyards” is disruptive to human activity, but also a contributor to other sources of carbon emissions. For example, during interviews with residents of Baghdad in 2022, one person noted, “*They cause a lot of traffic*.” Meanwhile, a young skateboarder from Baghdad told Rubaii, “*T-walls are such a nuisance. They make the city ugly and they cause so much traffic, always changing the routes and cluttering the roadways*.” While the impact of T-walls on traffic is not quantifiable, T-walls do contribute an observable addition to automobile traffic and its affiliated environmental costs.

5. Conclusion

Supply chains tend to be complex, making the data needed to conduct Life Cycle Assessments (LCA) difficult to obtain. More so, the procurement process of militaries, particularly during war time can be complex and secretive, involving global contractors, and sub-contractors. The privatisation of war, where some operations such as securing borders and rebuilding bombed cities are performed by third party companies makes access to data for carbon accounting a daunting task for researchers. In this paper, we have presented a framework or tracking and computing supply chain-based carbon emissions. Our framework is particularly handy where data is scant. The framework uses a hybrid LCA approach that draws on both input-output and process-based techniques by sectioning the model supply chain into stages – from cradle to grave. To ensure holistic assessment, the framework identifies five key stages of the supply chain – that is input material, production, point of use, end of life and transport. This allows systematic identification of emission sources, data requirements, and the uncertainties associated with the calculation. Our assessment indicates that the production phase of the supply chain mainly tier 2 input materials (cement and steel bars) contributed about three-quarters of total carbon emissions, while transport contributed between 22 to 24 percent.

Locally, people do not need carbon emissions calculations to understand the social and environmental impacts of the concrete industry. Certainly, those communities who were divide and controlled with T-wall installations by an occupying US military, and those who live close to cement factories run by multinational and regional corporations, understand what is at stake well-beyond quantified totals of carbon. The local impacts of unregulated or militarized concrete are palpable in peoples' daily lives at each stage of the supply chain. However, while responses to resist or mitigate these impacts are specific, local recourse is limited by the global scale of both military and multinational corporate enterprise. If we want governance of multinational corporations, we must also have tools for planetary engagement transnationally. Meanwhile, climate change action needs to see local components of the whole to be relevant.

In the spirit of LCA, which is to think locally to act globally, we have presented a case study of the supply chain of concrete T-wall procured during the US combat operations in Iraq between 2003 and 2008, and of the subsequent local environmental impacts.[16] This model demonstrates the need to account for each stage of the supply chain to avoid gross underestimations. Apart from cement, a carbon intensive material, the transportation of T-walls, from the production site in Erbil to the Green Zone and Sadr City in Baghdad, were major sources of military carbon emissions. Our framework highlights the strength of a hybrid process-based and input-output approach to carbon computation. A wide range of researchers benefit from methods that help to attain accurate calculations of carbon costs during wartime, whether those seeking stronger global emissions caps and reductions of military spending at COP28 (Crawford 2023), or those communities in Iraq seeking to reduce pollution of their

[16] While some of our other scholarship traces transnational supply chains beyond Iraq (eg weaponized metals Griffiths and Rubaii 2025), we have limited our focus here to local production of concrete T-walls for the sake of clarity. This does, however, lower the total emissions calculation were we to include the production and circulation of steel components of t-walls, which are not always produced locally.

aquifers and land at sites along T-wall the supply chain. In the absence of transparent reporting from the US military on its total emissions, we propose this method as a relatively reproducible one that enables scholars and policy makers to make informed estimates. Finally, we call for investment in more sustainable production methods for carbon-intensive materials such as cement and steel. Global pressure for militaries to have a roadmap for decarbonising should not ignore concrete materials, as it may not ordinarily be considered as a military consumable. We make this suggestion knowingly that a decarbonised US invasion of Iraq would still have been deadly and destructive to human and nonhuman life and therefore highlight, if anything, that calculating the massive greenhouse emissions of war could be used as evidence for a counter-argument, alongside others, to avoid such military violence in the first place.

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