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聚焦"双碳"（下）

近年来，我国公路交通行业高度重视"碳达峰""碳中和"，尽快实现"双碳"目标是行业关注的焦点问题。为此，本刊特邀相关专家从政策制定到工程实践等方面，介绍推动行业绿色低碳发展的新技术、新模式、新业态。

基于LCA的高速公路施工期碳排放量化边界界定

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摘要：交通运输是碳减排潜力最大、难度最高的领域之一，而公路交通碳排放在交通运输碳排放中占首位。为把握公路施工碳排放的特点，对工程建设碳排放进行有效盘查，该研究依托某高速公路建设工程，提出对高速公路施工期碳排放界定量化边界的方法。结果表明，通过LCA理论对高速公路施工期的碳排放边界界定，揭示了施工期碳排放的全过程，有助于准确核算公路施工期碳排放数量，为公路施工碳排放控制提供了重要依据。

关键词：LCA；碳排放；量化；边界

某一产品、活动、生产工艺或服务从"摇篮"到"坟墓"的过程是对其生命周期最直观的解释，即从原材料的获取，经生产、使用直至报废的整个环节。而生命周期评价(LCA)是通过制定某一系统有关整个环节的投入和产出的存量记录，评估整个环节相关环境因素和潜在影响的一种方法。

高速公路施工过程中的碳排放可通过材料为回溯源头开展溯源，但其施工过程冗余复杂，涉及材料数量巨大，本文需要根据实际工程的调研情况对研究过程进行量化分析，若过分追求量化研究内容的全面性和广泛性，则需要制定大量的假设条件，分析较深时不仅难以获取数据，而且容易导致误差传递，最后降低数据的可靠性。因此，需要合理界定量化边界。

1 施工材料全生命周期碳排放溯源

1.1 原材料生产阶段

高速公路施工期设计的原材料包括砂石、钢铁、水泥、沥青等原材料。国内多数研究者在研究过程中，只考虑原材料加工阶段为原材料的生产阶段。该研究中将原材料生产阶段分为两部分：第一阶段为原材料生产（上游阶段），此阶段包括原材料加工前的开采与运输到加工场地的过程；第二阶段为原材料生产（加工阶段），主要为原材料在运输至拌和场前加工至单个成品过程。

在该项研究中，原材料的上游制备阶段发生在材料生产商的场地内。因此，无法掌握其制备的具体能耗，只能选用文献调研和查表法，使用权威报告与标准中的因子核算的。

材料加工阶段的用料与用能均可以通过统计摸底排查到具体的数据。因此，使用具体统计与核算获得。综上，该项目原材料生产阶段量化边界条件的界定如图1所示。

1.2 原材料运输阶段

该项研究中原材料运输阶段分为两部分：第一部分为原材料从加工厂变成单个成品后运往预制厂、加工厂及拌和站的过程，即加工厂至"三厂"运输阶段；第二部分为经过加工或预制后的沥青混合料、预制件等运往施工现场的过程，即"三厂"至施工点运输阶段。原材料运输阶段量化边界条件的界定如图2所示。

1.3 施工建设阶段

原材料运送到施工点后，在施工点经过各种机械加工、摊铺、碾压、吊装等，变为公路工程形态，其量化边界如图3所示。

图1 原材料生产阶段量化边界条件的界定

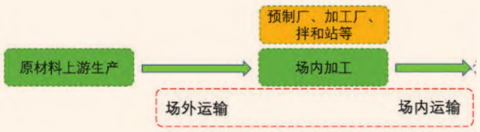

图2 原材料运输阶段量化边界条件的界定

图3 建设阶段机械耗能量化边界条件的界定

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2 基于量化边界的量化单元划分

以理论数据及实际调研数据为基础，对高速公路施工的生命周期范围中外界环境输出碳排放的量化是本文的研究重点。在量化边界条件后，须具体明确范围内能耗及碳排放的细节。定义每个范围内的若干单元过程，其能耗及气体排放总和即为最终量化结果。

2.1 能耗清单单元划分

能耗即为单位时间内能源的消耗，比如对于沥青路面建设过程来说，各个阶段主要消耗的能源过程侧重不同。原材料生产（加工阶段）主要集中在各原材料生产机械上；运输阶段主要集中在自卸汽车上；施工建设阶段主要集中在施工机械上，如摊铺机、振动压路机、拌和站等，其消耗能源类型也较为多种；大型生产加工机械主要消耗重油、煤、天然气、电能等；而运输施工机械主要以柴油、汽油、燃料油、电能为主。

随着人们对环境愈发重视而出台的相关环保制度、机械的更新换代、能源的逐渐清洁化替代等，能源消耗的类型也随之改变。故此部分内容首先对各阶段范围内研究细部进行初步单元定义划分，对于各单元的能源类型则视相关模型、文献调研和实际调研而定，以保证研究的时效性。

2.2 碳排放清单单元划分

碳排放一般指温室气体的排放。温室气体主要包括二氧化碳、甲烷、氧化亚氮、臭氧、氢氟碳化物等的排放，其中前三者对温室气体产生的温室效应最为突出。高速公路建设过程中，温室气体排放主要是由于各过程能源消耗和土地扰动所产生，以化石燃料燃烧为主，同时如电能、天然气的消耗也存在碳排放。此部分内容规定研究主要量化碳排放内容与能耗清单单元的划分一一对应，即主要量化上述各阶段消耗能源过程随之对应的碳排放量，且碳排放量只量化CO_2、CH_4、N_2O的排放。同时规定能源有效利用率为百分百转化，使其方便量化计算。碳排放清单单元划分如图4所示。

3 统计与核算原则

由于公路工程内涉及的材料、设备品种繁多，逐一分析过于复杂，所以为求抓住研究重点，只将满足以下4个原则之一的对象计入。

3.1 质量原则

将累计质量占总体质量95%以上的建材纳入计算范围。

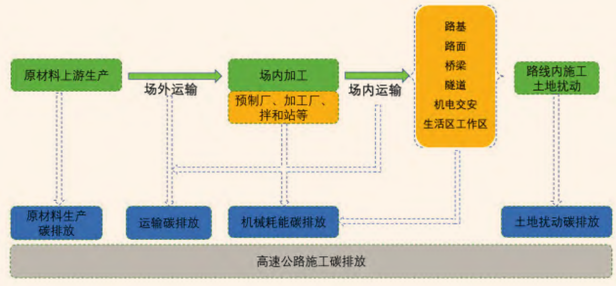

图 4 公路施工阶段碳排放清单单元

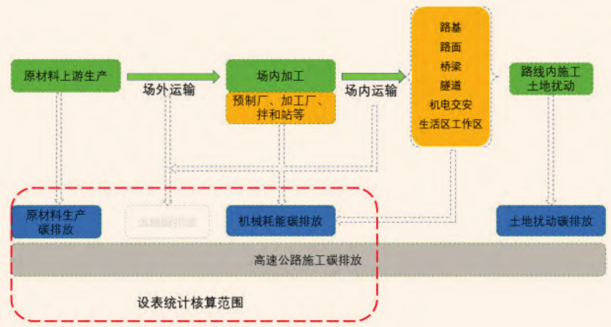

图 5 设表统计核算范围

3.2 造价原则

将累计造价占总体造价95%以上的建材纳入计算范围。

3.3 能耗原则

将累计能耗占总体能耗95%以上的机械、设备纳入计算范围。

3.4 权责一致原则

只将与公路建设单位主体权责一致的建材、机械、设备纳入计算范围，与之无关的（如临时借用的住房、电机等）不纳入计算范围。在该项研究中，实际消费的能源和用料纳入计算，力求做到不重不漏。

该研究采用统计法对某高速公路建设工程的机械用能和物料耗用进行统计。图5是该项研究设表统计的核算范围。

按照公路工程技术标准(JTG B01—2014)，将某高速公路建设工程的机械用能和物料耗用划分为路基工程、路面工程、桥梁工程、隧道工程、沿线设施、两区三厂六部分统计。在设计表格时，应考虑到在统计中所使用的机械设备、物料耗费等多方面内容，设计出对各分部工程有针对性的表格。

4 结语

通过LCA理论对高速公路施工期的碳排放边界界定揭示了施工期碳排放的全过程，有助于准确核算公路施工期碳排放数量。在未来，对公路施工碳排放控制提供了重要依据。

Focused on "Dual Carbon" (Third Chapter)

In recent years, Chinese highway transport industry has attached great importance to Carbon peak and carbon neutrality, and realizing the carbon peaking and carbon neutrality goals has been the focus of the whole industry. To this end, we invite relevant experts to introduce new technologies, new models and new business forms that promote the green and low-carbon development of the industry from the aspects of policy formulation to engineering practice.

Delimitation of Carbon Emission Quantification Boundary on Expressway Construction Period Based on LCA Theory

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Abstract: Transportation is among the most promising, but also most challenging areas for carbon emission reduction, in which highway transportation is the major source of carbon emissions. This study aims to define quantification boundary of the characteristics of carbon emissions from highway construction, and to provide a reference for carbon emissions calculation from engineering construction. The findings show that delimitation of carbon emission boundary for expressway construction period through LCA theory will benefit accurate accounting of carbon emissions in expressway construction period, while providing an important reference for the control of carbon emissions in highway construction.

Keywords: highway construction;carbon emissions;construction period;boundary delimitation

The process of a product, activity, production process, on a service from "Cradle" to "Grave" is the most direct interpretation to its life cycle, and the process refers to the entire link covering acquisition of raw materials, production, utilization, and scrapping. Life Cycle Assessment (LCA) is a sort of method in which stock record for input and output of the entire link of a system is made so as to assess relevant environmental factors and potential impacts of the entire link. During expressway construction process, the carbon emissions may be traced while materials are taken as a traceable source. Despite this, the construction process is highly complicated and involves an enormous number of materials, thus this paper needs to make a quantitative analysis of the research process according to real engineering survey results. In case of excessive pursuit of comprehensive and extensive quantitative research contents, we need to set a host of assumptions, and further analysis will lead to difficulty in acquisition of data, which might bring about propagation of error and reduction of data reliability. Therefore, it is necessary to delimit quantification boundary in a reasonable fashion.

1 Carbon Emission Tracing In Life Cycle of Construction Materials

1.1 Raw Material Production

Raw materials for expressway construction include sand and stone, steel, cement, and asphalt, etc. During the research course, most researchers in China only consider raw material processing as raw material production. In this paper, we divide raw material production into two stages: Stage 1 refers to raw material production (upstream stage), and it involves the process from exploitation of raw materials to transportation of raw materials to the processing site; Stage II refers to raw material production (processing stage), in which raw materials are processed into a single product before they are transported to the mixing yard. In this research, upstream production of raw materials takes place within material manufacturer's yard, so we are unable to know specific energy consumption in the production, so

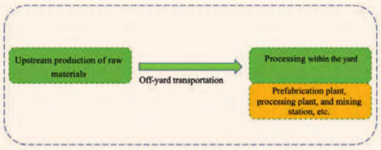

Fig1. Delimitation of quantification boundary conditions at raw material production stage

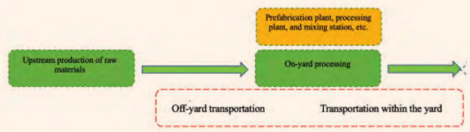

Fig2. Delimitation of quantification boundary conditions at raw material transportation stage

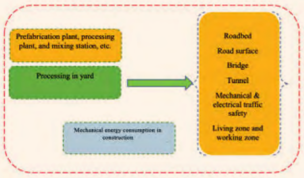

Fig3. Delimitation of quantification boundary conditions for mechanical energy consumption at the construction stage

we adopt literature research and instance approach and leverage authoritative report and factors in the standard for calculation. For material processing, since it takes place in this project, we can get specific data on material and energy consumption through statistics and investigation, thus the data arises from sum-up and calculation. So, see Fig. 1 for the delimitation of quantification boundary conditions at raw material production stage.

1.2 Raw Material Transportation

In this research, raw material transportation also falls into two stages: Stage I refers to the process in which raw materials are changed into a single product at the processing plant and then transported to a prefabrication plant, processing plant, and mixing station, and it is also called "Processing Plant-Transportation to Three Plants (Reinforcement processing plant, mixing plant and prefabrication plant)" stage; Stage II is the "Three Plants-Transportation to Construction Site" stage, in which processed or prefabricated bituminous mixture and prefabricated members are transported to the construction site. See Fig2 for the delimitation of quantification boundary conditions at raw material transportation stage.

1.3 Construction Stage

After being transported to the construction site, raw materials will be subjected to mechanical processing, spreading, and roller compaction and hoisting at the construction site, and changed into highway engineering form. See Fig. 3 for the quantification boundary.

2 Classification of Quantification Unit Based on Quantification Boundary

In this paper, we, based on theoretical data and investigation data, focus on research of quantification of carbon emissions to external environment during life cycle of expressway construction. After delimitation of quantification boundary conditions, details of energy consumption and carbon emission within specific scope must be clarified. In definition of multiple units within each scope, the sum of energy consumption and gas emissions is the final quantification outcome.

2.1 Classification of Energy Consumption Inventory Unit

Energy consumption refers to consumption of energy per unit of time. For example, energy consumption process differs in construction of asphalt pavement: raw material production machinery consumes most energy in raw material production (processing stage); dump truck consumes most energy at the transportation stage; construction machinery (including paver, vibrating compactor, and mixing station) consumes most energy at the construction stage. In addition, there are numerous types of energy consumed: large-scale production & processing machinery likely consume heavy oil, coal, natural gas, and electric energy, etc., whereas transportation construction machinery is probably driven by diesel oil, gasoline, fuel oil, and electric energy. Due to a series of factors such as more and more attention to environmental protection, promulgation of relevant environmental protection rules, upgrading of machinery, and clean use of energy, types of energy consumed change accordingly. In this part, we first define preliminary unit of research segment for each stage, and determine energy type of each unit according to relevant model, literature research, and real research results, in order to assure the research timeliness.

2.2 Classification of Carbon Emission Inventory Unit

Carbon emission usually refers to GHS emission. Greenhouse gases (GHG) mainly include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone, HFCs, PFCs, and sulfur hexafluoride, etc., of which, the first three gases contribute most to greenhouse effect resulting from GHG. During expressway construction process, GHG emissions mainly arise from energy consumption and land disturbance, in which fossil fuel burning predominates. In addition, consumption of electric energy and natural gas leads to carbon emissions. In this part, qualification of carbon emissions must match classification of energy consumption inventory unit. In other words, we will mainly quantify carbon emissions relating to energy consumption in aforesaid stages. And carbon emissions are quantified only for CO2, CH4, and N2O emissions. Meanwhile, the

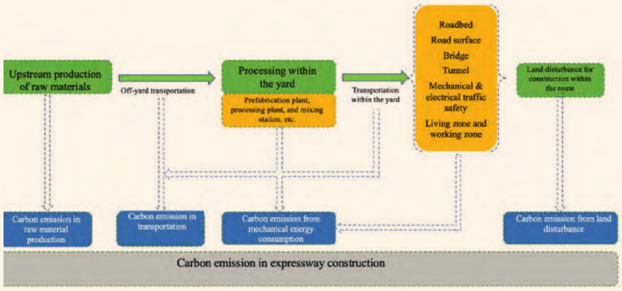

Fig4. Carbon emission inventory unit at the highway construction stage

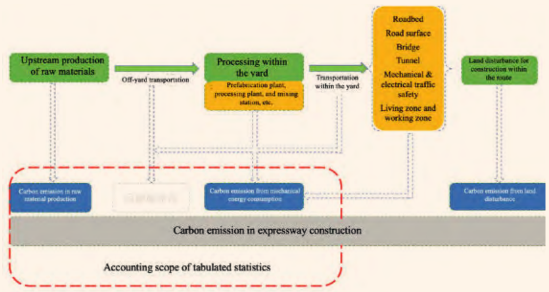

Fig5. Accounting scope of tabulated statistics

effective energy utilization rate is established as 100% conversion to make it easy to quantify the calculation.

See Fig 4. for the classification of carbon emission inventory unit.

3 Statistics and Accounting Principle

Since highway engineering involves a variety of materials and equipment and it's difficult to make analysis one by one, we only research objects that meet one of the following three principles, in order to facilitate the research.

1)Mass principle: include building materials (cumulative mass accounting for above 95% of total mass) in the calculation scope.

2) Cost principle: include building materials (cumulative cost accounting for above 95% of total cost) in the calculation scope.

3) Energy consumption principle: include machinery and equipment (cumulative energy consumption accounting for above 95% of total energy consumption) in the calculation scope.

4) Principle of responsibility in accord with authority: only include those building materials, machinery, and equipment (to which the highway construction unit has responsibility in accord with authority) in the calculation scope, and exclude irrelevant factors (such as temporary housing and motor for use). In this project, we include the actually consumed energy and materials in the calculation, in order to live up to no repetitive or missing calculation.

In this research, we adopt statistical approach to sum up mechanical energy consumption and material consumption of A Expressway Project. See Fig. 5 for the accounting scope of tabulated statistics in this research.

Pursuant to Technical Standards of Highway Engineering (JTG B01-2014), we classify mechanical energy consumption and material consumption of Daqing-Guangzhou Expressway Nanlong Expansion Project into roadbed works, pavement works, bridge works, tunnel works, facilities along the line, and "Two Zones (Work zone and living zone), Three Plants". When devising the table, we make special tables for each work while taking into account machinery, equipment, and material consumption etc. in the statistics.

4 Conclusions

Delimitation of carbon emission boundary for expressway construction period through LCA theory will benefit accurate accounting of carbon emissions in expressway construction period, while providing an important reference for the control of carbon emissions in highway construction.

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