



# Life cycle assessment of Mexican polymer and high-durability cotton paper banknotes



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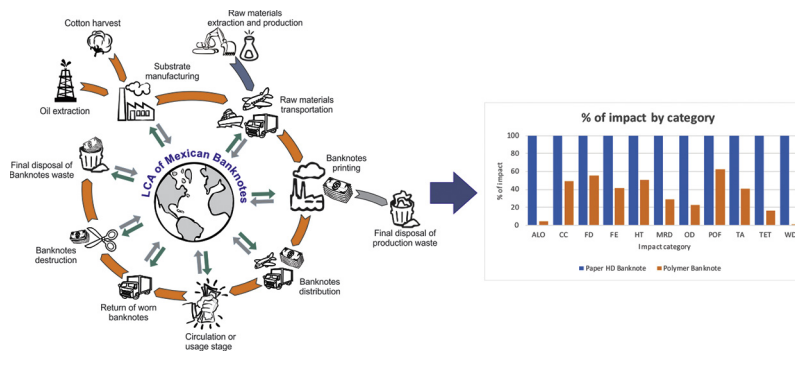
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## HIGHLIGHTS

- Banknotes printed on polymer substrate present lower environmental impacts.
- The stages of extraction of raw materials and distribution have a mayor impact.
- Impacts depend of the lifespan of banknotes, which is different for each substrate.
- Electricity required during the use is determining for the environmental impacts.

## GRAPHICAL ABSTRACT



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## ABSTRACT

This study compares the environmental performance of Mexican banknotes printed on high-durability cotton paper (HD paper) and thermoplastic polymer (polymer) through a life cycle assessment to appraise the environmental impacts from the extraction of raw materials to the final disposal of the banknotes. The functional unit was defined considering the next parameters: 1) lifespan of the banknotes, established in 31.5 and 54 months for HD paper and polymer, respectively; 2) denomination, selecting \$200 pesos banknotes; 3) a 5 year time frame and 4) a defined amount of money, in this case established as the monthly cash supply of an average Mexican household, equaling \$12,708 pesos. Accordingly, 121 pieces for the HD paper and 71 pieces for the polymer banknotes were analyzed. The results favor the banknotes printed on polymer substrate primarily because of the longer lifespan of this type of material; however, there is a considerable environmental impact in the stages of distribution, followed by the extraction of the raw materials (crude oil) during manufacturing. Regarding the HD cotton paper, the major impact corresponds to extraction of the raw materials, followed by the distribution of the banknotes. The inclusion of the automatic teller machines (ATMs) in the life cycle assessment of banknotes shows that the electricity required by these devices became the largest contributor to the environmental impacts. Additionally, the sensitivity analysis that the average lifetime of the banknotes is a determining factor for the environmental impacts associated with the whole life cycle of this product. The life cycle stages that refer to the extraction of the raw materials, combined with the average lifetime of the banknotes and the electricity required during the usage stage, are determining factors in the total environmental impact associated with Mexican banknotes.

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## 1. Introduction

One of the main factors influencing the environmental deterioration currently present at the global level is the patterns of production and consumption developed in recent years, as these exceed the capacity of the planet to adapt, causing an excessive depletion of resources, continuing environmental deterioration and significant social and economic problems (UNEP, 2015; SEMARNAT, 2013).

As a result, a transition to new productive practices and sustainable consumption patterns focused on preserving the environment are necessary, seeking to reduce the usage of resources and the generation of pollutants throughout the life cycle of products and services (UN, 2012). Ideally, such actions lead to a competitive economy featuring sustainable supply links, creating awareness of the conservation of natural capital for the decision makers and social actors involved.

Mexico has subscribed to the Marrakesh Process promoted by the United Nations Environment Program (UNEP, 2011) through the National Strategy for Sustainable Production and Consumption (Estrategia Nacional de Producción y Consumo Sustentable - ENPCS) (SEMARNAT, 2013). The process goal is the implementation of programs to accelerate the transition to sustainable principles on production and consumption patterns in a global framework: which is in turn prompted by the Johannesburg Plan of Implementation of the World Summit on Sustainable Development (UN, 2002). Therefore, the ENPCS, promotes economic stimuli to identify problem areas that could incorporate new technologies as alternative to reduce the environmental impact. Consequently, the ENPCS has adopted international production standards, describing indicators to measure sustainability and, regulating materials through product life cycle approach in production processes, supplies procurement and consumption of goods and services (SEMARNAT, 2013).

For this reason, Bank of Mexico, driven by its commitment to national and international consensus on sustainable and environmentally efficient products (SEMARNAT, 2013; Government of the Republic, 2013; DOF, 2012), has requested an assessment of the environmental impact that the banknotes generate throughout their life cycle. The study was conducted based on ISO 14040/44 (ISO, 2006).

In this context, the banknote is defined as a globally accepted medium of trade, with which operations are conducted at the international level and which, throughout history, has been a tool for economic development, facilitating the exchange of goods (Kraxenberger et al., 2013). It is an instrument that millions of people handle, associated with more than 100 billion pieces annually in the world (Muehlfelder, 2013); therefore it is necessarily a durable and environmentally viable “product” that does not pose a health risk to those who handle it. In this respect, it is important to understand the environmental impact associated with its production (Fiori, 2013).

Studies conducted in North America, Latin America and Europe indicated that banknotes accounted for 96–98% of the cash in circulation worldwide from 2007 to 2011; with a proportional relation between banknotes in circulation per inhabitant in all geographical areas studied. According to Negueruela (2013), in Latin America the number of banknotes in circulation increased 8% annually. Likewise, cash in circulation continues to increase in the United Kingdom (The Global Magazine of De La Rue, 2012) and New Zealand (Boaden, 2008) despite the increase in electronic means to carry out financial transactions. In United States, consumers use cash for low-value daily transactions (playing a critical role when there are no other options available), or when they have lower purchasing power (Narron and Bennett, 2014; Angrisani et al., 2012).

The use of cash is closely related to traditions and economic income (Bertoncelj and Godler, 2014). The informal commerce induces to trade banknotes for goods in a traditional way to reduce “technology error” between users. According to the World Bank, this informal sector plays a fundamental role in Latin America and the Caribbean, representing 40% of the region’s economy (ONU-Habitat, 2012). Therefore, the expansion of electronic money does not imply a threat for

banknotes, rather a parallel growth in which banknotes coexist as valid and complementary means of payment.

Paper money offers the possibility of configuring a wide variety of designs security elements in the banknotes of each country or region, integrating properties such as durability, handling and efficiency in production costs. Among these properties, the durability factor, which has been of great interest to the Central Banks, is particularly important because a more durable banknote reduces the replacement rate and therefore the manufacturing effort required to supply the demand. As a result, substrate manufacturers have developed various materials that improve banknote characteristics (Meuer and Martin, 2011; González and Schweckandt, 2011; Crane, 2011; Singh, 2008), resulting in long-lasting materials as high-durability cotton paper (HD paper) and polymer.

The performance of banknotes around the world varies according to external factors such as climate, humidity, temperature, banknote denomination and usage habits, among other factors (Antoci, 2011; Geusebroek et al., 2011). Since these factors determine banknote durability, it is important to consider the conditions of use and the country climate conditions (Chalhoub and Hamdan, 2015; Kyrchok et al., 2014; de Heij, 2002).

Circulating Mexican banknotes currently consist of two types of material: those containing cotton fiber in denominations of \$100, 200, 500 and 1000 and those containing polymer in denominations of \$20 and 50. The Bank of Mexico produces approximately 1300 million banknotes annually (Banxico, 2014) through an industrial process involving the extraction of natural resources, transportation of raw materials, fabrication of paper money, distribution, energy consumption, and waste generation and disposal.

Based on the above context, the purpose of this study is to compare the environmental impact of the \$200 pesos banknote printed on two types of substrates (printing material), high durability cotton paper (HD paper) versus thermoplastic polymer (polymer), under the conditions of use in Mexico through a life cycle assessment (LCA) that aims to identify opportunities for improvement in environmental terms throughout the life cycle of the banknote.

There are currently no published scientific articles that show the environmental impacts generated by the life cycle of the banknotes, only reports of projects conducted by Marincovic et al. (2011) for the Bank of Canada and Shonfield et al. (2013) for the Bank of England. Thus, this study shows relevant implications in two topics: 1) life cycle inventory integration of banknotes is complicated to obtain due its highly secure production chain, and its economic value reduce the possibility of data acquisition due probable information deflection for non-legal purposes; 2) functional unit included conditions of use, therefore, the lifespan of the two banknotes varieties studied.

## 2. Methodology

The function of the system is to provide a physical medium, such as banknotes, to conduct business transactions that allow the acquisition of goods and services.

For the two types of substrate, the complete life cycle is considered, from the extraction of raw materials, the process of manufacturing and transportation of these elements, the manufacture of the banknote, its distribution, the usage stage, the return of worn banknotes to the Central Bank, and their destruction and disposal at the end of their useful life, considering all the inputs and outputs of each unit process, including the required transportation Fig. 1.

The reference year for the data used in the development of the life cycle inventory corresponds to the representative information of the factory production from the Bank of Mexico during 2013, equivalent to 1,440,000,000 pieces of banknotes, since these data are considered relatively complete and of high quality.

The distribution and use of the banknote is constrained to Mexico. Data on the stages of printing, distribution, banknote destruction and

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