Freie Universität Berlin
Department of Political and Social Sciences
Environmental Research and Policy Center

Technische Universität Berlin
Department Planning, Building, Environment
Institute Landscape & Environmental Planning

Master's Thesis

Using Revenues from Carbon Pricing to Close Infrastructure Access Gaps
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Distributional Impacts on Nigerian Households

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Dr. Jan Christoph Steckel

Department Economics of Climate Change

Technische Universität Berlin

Dr. Michael Jakob

Mercator Research Institute on Global Commons and Climate Change

Ira Dorband

Unterer Steinberg 6
97453 Schonungen-Forst
ira_dorband@yahoo.de

Master Environmental Policy and Planning
Matriculation Number: 4792904

Abstract

Carbon pricing has been recognized to be the most efficient means for climate change mitigation. However, especially in developing countries, there is concern that respective policies jeopardize development and disproportionately burden the poorest parts of the population. This paper analyzes the distributional impact of an economy-wide carbon tax and fossil fuel subsidy reform on households in Nigeria, Africa's largest economy. Tax revenues and subsidy savings are assumed to be invested into basic infrastructure provision. The distribution of tax payments as well as of infrastructure access gaps across income groups is estimated by combining an environmentally-extended input-output model with household survey data. While in developed countries distributional impacts of carbon pricing have been studied abundantly, studies on developing countries using this method are relatively scarce. In line with previous developing country studies, a carbon tax or subsidy reform are found to be progressive in Nigeria. Furthermore, access gaps impair primarily rural, lower income households. A comparison of total revenues and costs shows, however, that universal infrastructure access provision until 2030 is unlikely to be financed solely through carbon pricing. These results suggest that a carbon tax recycled into infrastructure not only poses a better targeted means of redistribution than the existing subsidy regime, but also entails relevant environmental and human development benefits.

Key Words: Carbon Pricing; Fossil Fuel Subsidies; Infrastructure Investment; Household Data; Nigeria

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1. Introduction

Two defining challenges of this century are overcoming poverty and managing climate change.

(Stern 2015)

The alleviation of poverty and the stabilization of the climate are intrinsically intertwined as success in rising to one, necessitates success in rising to the other. The impacts of climate change are most detrimental to poorer populations in often less resilient developing countries, undermining achieved progress in poverty alleviation and development (UN 2015a; IPCC 2014). However, throughout past decades both in science and in the public debate, the notion was widespread that meeting the two challenges was mutually exclusive because mitigating climate change was seen as a costly burden and immanently antithetical to development (Stern 2015). India's former environment minister Jairam Ramesh most prominently represented this view when he stated that (what was perceived as) the failure to agree on an international climate change treaty with binding mitigation targets in 2009 protected the right to continued economic growth for the world's emerging economies (ABC News 2009).

In this spirit, under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC 1998) only industrialized countries were obliged to reduce their greenhouse gas (GHG) emissions. However, global emissions have continued to rise steadily despite of the goal stipulated by the UNFCCC (1992) to cap GHG emissions to prevent dangerous anthropogenic interference with the climate system. While today's developed countries are responsible for the largest share of GHG emissions currently accumulated in the atmosphere (IPCC 2014), within the last decade growth in emissions came almost entirely from large developing countries (Stavins and Keith 2016). Evidence, for example from China, suggests that successful poverty alleviation and economic development in recently emerging economies came along with large-scale burning of fossil fuels, respective carbonization and convergence to developed countries' levels of energy demand (Jakob, Haller, and Marschinski 2012; Steckel et al. 2011). If all developing economies were to follow this path, locking in high future emissions through carbon-intensive infrastructure development, climate protection would fail (Steckel, Edenhofer, and Jakob 2015; Ottmar Edenhofer et al. 2015). In the 2015 Paris Agreement (UNFCCC 2015) the international community came to terms that the 2 °C climate change mitigation goal adopted under the UNFCCC necessitates active participation in mitigation efforts of all countries, irrespective of their level of income. Furthermore, the international community of states is increasingly recognizing the potential complementarity and positive synergies between climate responsibility, economic development and poverty alleviation postulated by Stern (2015). Emphasizing the interdependence of economic, environmental and social prosperity, the global agenda of the Sustainable Development Goals (SDGs) was adopted in 2015 and the concept of green growth has found widespread recognition (c.f. e.g. OECD 2016; World Bank 2012; UNEP 2011).

Pursuing the idea of sustainable development, it remains a challenge to define political measures which can reconcile economic development with climate change mitigation, particularly on national level in developing countries. Jakob et al. (forthcoming) analyze the potential of carbon pricing to finance the closing of infrastructure access gaps on a global level. Motivated by Jakob et al. (forthcoming) and Jakob et al. (2015), this paper examines the interplay of the two policy measures, namely a carbon pricing reform coupled with infrastructure development, on national level in Nigeria. The paper argues that carbon pricing in the form of a subsidy and tax reform would not only induce cost-effective GHG emission reductions in Nigeria, but could also contribute to economic and human development as well as, most importantly, to the reduction of inequality by freeing the financial resources necessary to provide access to basic infrastructure, including water, sanitation, electricity and telecommunication. Based on the case of Nigeria, the analysis specifically focuses on the policies' overall effects on income distribution and inequality.

The analyzed policy mix is expected to make climate change mitigation measures politically more attractive, especially in Nigeria, as it links them to the achievement of crucial development goals: Carbon pricing in theory is seen as the most efficient policy instrument to mitigate climate change, ideally being harmonized across the globe (IPCC 2014). While a harmonized global carbon price is rather unlikely in the near future, there are good reasons for countries to levy domestic carbon prices, including internalization of domestic climate impacts, co-benefits, and public finance considerations (Edenhofer et al. 2015). While around 39 national jurisdictions had implemented or planned carbon prices between US$ <1 and US$ 130 per ton CO_2 equivalent (tCO_2 e) in 2015 (World Bank 2015a), another 39 countries were subsidizing fossil fuel consumption at an average subsidization rate of 38 percent in 2014 - practically putting a negative price on carbon (IEA 2015a). While the former are almost entirely high income countries (World Bank 2016b), the latter are mostly developing countries who remain, as expected, in particular reluctant to raise carbon prices.

Revenue recycling into infrastructure development is expected to critically dampen political and public contestation of carbon pricing. Apart from the concern that carbon pricing jeopardizes overall economic development, its political feasibility has been found to be mainly influenced by the widespread perception of respective policies to be regressive, i.e. to disproportionally burden the poorest parts of the population (Gevrek and Uyduranoglu 2015). In reverse, fossil fuel subsidies are widely considered to be an effective tool for protecting the poor and decreasing societal inequality (Arze del Granado, Coady, and Gillingham 2012). This paper hypothesizes that investing revenues in the provision of basic infrastructure would specifically counteract negative distributional effects and compensate lower income households for their carbon-price-induced loss of real income because poorer households are typically thought of as less likely to have adequate access to infrastructure. Independent of actual distributional outcomes, public acceptance can also be drastically enhanced by earmarking reform revenues for redistributive measures, i.e. by linking them to defined increases in pro-poor public expenditures (Gevrek and Uyduranoglu 2015; Sælen and Kallbekken 2011). Furthermore, widespread access to basic infrastructure has been determined as a prerequisite for sustainable development (Griggs et al. 2013). However, mostly due to insufficient financial resources, current levels of infrastructure provision have been identified as sub-optimal and infrastructure investments are expected to make up the largest share among all sectoral investment needs to achieve the SDGs (UNTT 2015). Carbon pricing can serve as promising mechanism to yield the necessary additional public revenues (N Stern and Calderon 2014; World Bank 2013).

Finally, the analyzed policy mix seems particularly promising in Nigeria due to the high current and projected growth rates of the country’s economy and population. A carbon pricing reform coupled with clean infrastructure development might provide an opportunity to prevent locking-in new carbon-intensive infrastructure as well as leaving behind poorer segments of society throughout the growth process. In 2014 Nigeria grew to be Africa's largest economy, reaching a GDP of US$ 657 billion in 2015, while its population is projected to grow to 440 million by 2050 which would make it the world's third most populous country, only behind China and India (D. Coady et al. 2015; PRB 2013; UN 2015b). If no significant mitigation efforts are undertaken, Nigeria's GHG emissions are expected to double by 2035 (Cervigni, Rogers, and Henrion 2013). Nigeria would then emit around 660 million tons of GHGs annually, thus outpacing Germany by 2035 (BMUB 2015). Furthermore, steeply rising energy demand, especially in the residential sector, necessitates the rapid expansion of the power sector which is expected to account for the largest share of emission growth in Nigeria, and, thus, has the highest mitigation potential (GIZ 2015; Cervigni, Rogers, and Henrion 2013). However, necessary public investments have been constrained due to large fiscal deficits. Nigeria's public budget is highly vulnerable to volatile global fossil fuel prices due to its large resource dependency as well as high expenditures on the existing fossil fuel subsidies. Importantly, in its Intended Nationally Determined Contribution (INDC) submitted to the UNFCCC in 2015, the Nigerian Federal Government signals to be in favor of respective policies and acknowledges their co-benefits. It states that ambitious mitigation action is economically efficient and socially desirable in Nigeria, even apart from its climate benefits (FME 2015). Specifically, it recognizes that "fiscal reform is proving [*sic*] an efficient mitigation action [because it] releases significant resources in the budget that can fund investments in efficient infrastructure" (FME 2015). In this spirit, in early 2016, the government partially abolished the existing subsidy on kerosene and petrol and efforts have been undertaken to ramp up public investment in infrastructure provision (FMF 2011; FMF 2015; Bloomberg 2015).

Contributing to previous literature in several ways, this paper analyzes the impact on income distribution, first, of a carbon pricing reform, second, of infrastructure development and, third, of their interplay in Nigeria: First, it estimates the total and relative loss of households' incomes as well as the distributional effect of both a potential economy-wide carbon tax as well as of a complete subsidy removal. While payments arising from carbon taxation are estimated based on households' direct and indirect consumption-based emissions, households' subsidy revenues are calculated based only on their direct fuel consumption. Calculations of carbon emissions combine data from a 2011 environmentally-extended input-output model with data from a 2010/2011 representative household survey in Nigeria. Distributional impacts are estimated across rural and urban household quintiles based on per capita income. Secondly, the paper analyzes the distributional impact of potential universal infrastructure provision, estimating current access gaps based on qualitative survey questions. Thirdly, it estimates total revenues from carbon taxation and total infrastructure investment needs to provide universal access by 2030 and compares to what extent the latter could be achieved. For the case of Nigeria, these analyses allow insights, first, regarding the overall impact of the policy mix on income distribution and inequality and, second, regarding the potential of carbon pricing as financing mechanism for sustainable development. Importantly, these analyses contribute to the literature as developing country studies on the distributional effect of comprehensive carbon pricing, using the described method, are scarce and have not been conducted in Nigeria.

Moreover, to the best of knowledge, there are no previous studies analyzing the distributional impact and overall potential of carbon pricing in relation with infrastructure development on national level.

The remainder of this paper is organized as follows: Section 2 reviews relevant literature, sections 3 provides brief background information on Nigeria. Sections 4 and 5 outline the data, describe in detail the underlying calculations of the respective analytical steps and potential methodological limitations and present first descriptive results. Section 6 presents the results of the analyses, and section 7 provides a discussion of the results and concluding remarks.

2. Literature Overview

Centering on the analysis of the distributional effects of the policy mix of carbon pricing coupled with infrastructure development, this study ties in with a wide range of literature analyzing feasible options for national and international climate change mitigation policies at the nexus with socio-economic development. An overview of previous literature, first, introduces the challenges of mitigation, referring particularly to the development context. After a brief review of global commons considerations generally, the prevailing disincentives for unilateral emission reductions in developing countries are highlighted specifically, namely the concern of impairing overall economic performance as well as slowing down poverty and inequality alleviation. Second, evidence from previous studies is presented on how carbon pricing and infrastructure investment could overcome specifically these concerns and serve as attractive mitigation policy due to positive synergy effects on sustainable economic and human development. Finally, the state of the art concerning distributional effects of comprehensive carbon taxation, of subsidy reform as well as of infrastructure development is presented in detail and how this paper intends to further existing evidence by analyzing the case of Nigeria.

2.1. The Problem Statement: Collective Action and Mitigation in the Development Context

Collective action theory or the tragedy of the commons (Hardin 1968) suggest that due to the global public good character of the atmosphere whose use is perfectly non-exclusive and not immediately rival climate protection will be supplied at a socially sub-optimal level. The theory suggests that in the absence of a global enforcement mechanism unilateral mitigation efforts do not satisfy countries' self-interest due to expected free-riding (Barrett 2003; Barrett 1994). Instead of contributing to the long-term globally optimal level of supply, countries have an incentive to pollute and maximize their own short-term benefits, foremost stemming from cheap emission-intensive energy supply. Especially regarding large-scale power generation capacities, fossil fuels still constitute the cheapest source of energy (IPCC 2011) - when disregarding their negative climate and environmental externalities, like emissions and air pollution. The cost of energy in developing countries would thus increase from mitigation measures such as the deployment of low-carbon alternatives, like renewables or nuclear power, or carbon-tax-induced price changes of fossil resources (Schmidt, Born, and Schneider 2012). Especially developing countries have been reluctant to voluntarily undertake efforts to reduce their emissions, while struggling to supply their rapidly growing energy demand (Jakob et al. 2014).

Two major concerns prevail regarding the adverse impact of climate change mitigation on development prospects, first, on overall economic growth and, secondly, on the alleviation of poverty and inequality: First, in the past socio-economic development was closely correlated with energy demand (Costa, Rybski, and Kropp 2011; Gruebler 2004). Steckel et al. (2013) show that no country has succeeded in achieving high income levels without having crossed a certain threshold of per capita energy consumption. Also in the last two decades economic growth in China and other developing countries came along with a convergence of their energy demand to that of developed countries (Jakob, Haller, and Marschinski 2012; Steckel et al. 2011). The move into energy-intensive industry has been identified as a stepping stone to development (Galor 2005) and the energy-intensive expansion of physical capital has been found to play a crucial role in the growth process (Calderón and Servén 2014; Steckel et al. 2011; Jan C Minx et al. 2011).[1] Higher energy prices induced by mitigation efforts result in higher prices of capital goods and are thus suspected to crowd out infrastructure investments and delay industrialization.

Second, higher energy prices might not only impede economic growth and thereby impair developing countries in lifting their population out of poverty, but also disproportionally burden the poor and increase inequality. In developed countries, most studies on the distributional effects of carbon tax payments find regressive welfare impacts with poorer households spending larger shares of their income on energy. For developing countries, empirical evidence is mixed and distributional effects depend strongly on the country-specific context

[1] Literature on this connection will be analyzed in further detail below.

(Sterner 2012a).[2] However, irrespective of the distributional outcome relative to income, any additional tax-related payments will compromise the real income of poorer households. Furthermore, higher prices of fossil energy might directly impair individual energy access when alternative low-emitting energy sources are also more expensive (Jakob and Steckel 2014). Such price changes might trap poorer households in the use of cheap, but emission-intensive traditional biomass and jeopardize a key element of any sustainable development strategy, namely universal, clean and reliable energy access (Griggs et al. 2013; IPCC 2011).

Against this theoretical and empirical background, it can be concluded that climate policies have to be formulated in a larger sustainability framework, deliberately supporting socio-economic development and redistributing in favor of the poor. Accordingly, Ostrom (2010) states that policies which predominantly serve non-climate-related development objectives, but which at the same time result in substantial emission reductions as co-benefits, have the biggest chance to be unilaterally implemented and to make a meaningful contribution to climate mitigation. This basic idea of incentivizing domestic climate protection through a multiple-objective policy framework has found widespread resonance in the international debate in concepts like Green Growth and the Sustainable Development Goals (SDGs) (World Bank 2012; UNEP 2011) as well as in research (a.o. Ottmar Edenhofer et al. (2015)).

2.2. The Potential of Carbon Pricing and Infrastructure Provision

This paper suggests that domestic carbon pricing coupled with infrastructure provision can be the entry point to a successful multiple-objective policy mix to reconcile change climate mitigation and development on national level. This rational is based on a multitude of arguments derived from previous literature on this topic. This subsection, first, introduces carbon pricing as an efficient mitigation instrument and highlights its potential domestic economic co-benefits, including the collection of revenues. Second, it outlines the benefits of targeted revenue recycling into infrastructure development:

From an economic perspective, carbon pricing has been recognized as an important prerequisite for cost-effective climate change mitigation (Edenhofer et al. 2015; IPCC 2014). Ideally, the price level would be chosen to fully correct social and environmental externalities of carbon emissions and, thus, lead to optimal abatement efforts (Pigou 1920). However, even lower-than-optimal prices are preferable to none as the idea behind such market-based policy instruments is that any price signal will at least partially internalize previous market failures

[2] Literature on the distribution of welfare impacts will be further introduced below.

into the decisions of market participants (Edenhofer et al. 2015; L. H. Goulder and Parry 2008). Often the initial most cost-effective abatement is achieved through fuel switch, energy saving and efficiency measures which have a high chance of being incentivized by the price signal. This is also the case in Nigeria. Analyzing the Nigerian energy system, Oyedepo (2014) defines the inefficient utilization of energy as a major challenge in the country's struggle for adequate supply. Accordingly, investment in energy efficient light bulbs, fuel efficiency, improved kerosene cook stoves, more efficient electrical appliances or the reduction of gas flaring among others has been identified to yield abatement at very low or even negative costs (Cervigni, Rogers, and Henrion 2013; FME 2010).

By incentivizing such low-carbon practices, a carbon pricing reform entails not only reduced GHG emissions, but also significant domestic co-benefits both on the micro- and the macroeconomic level: First, the mentioned domestic abatement measures substantially reduce domestic social and environmental external costs as they abate not only greenhouse gases and their long-term domestic climate impacts, but also other air pollutants, yielding immediate local co-benefits for air quality and human health. Based on a survey of 37 previous studies, Nemet, Holloway, and Meier (2010) estimate the economic benefits of air quality improvements induced by climate mitigation. They find a range between US$ 2 and US$ 196 per ton of abated CO_2 across several countries, with the highest co-benefits in developing countries. Analyzing the long-term health benefits of mitigation between 2030 and 2100, West et al. (2013) find that in several world regions the average marginal co-benefits of avoided mortality exceed marginal abatement costs by a magnitude of 10 to 70. Further localized benefits of reduced fossil fuel use can arise from reduced congestion through reduced travel time, physical activity and ambient noise (Creutzig, Mühlhoff, and Römer 2012; Duranton and Turner 2011). Based on an assessment of the ten countries with the highest fuel subsidies, Davis (2016) estimates the global external social and health costs of subsidizing fossil fuels at US$ 44 billion annually. Secondly, apart from foregoing domestic pollution and related external costs, subsidy removal or carbon pricing are hoped to directly enhance overall economic performance and growth. By encouraging investment in energy efficiency and renewables, positive carbon prices are hoped to result in more efficient use of economic resources, increased technological innovation, additional employment opportunities and thereby green growth (UNEP 2011; OECD 2016). Even though these synergy effects are likely to be smaller than expected (Allcott and Greenstone 2012), cost savings from price-induced additional energy efficiency measures and increased technology spill-overs among sectors are still expected to enhance overall economic performance (Ottmar Edenhofer et al. 2015; Staub-Kaminski et al. 2014).

Apart from these domestic economic co-benefits, importantly carbon pricing and subsidy removal can serve as a direct source of revenue (or savings) and have been identified as a promising mechanism for post-2015 development finance by the World Bank (2013) and Rietveld and van Woudenberg (2005). Subsidy removal has been found to entail large direct and indirect fiscal savings because fossil fuel subsidies are fiscally expensive and economically inefficient. In 2014 direct fossil fuel subsidy spending totaled at around US$ 493 billion[3] (IEA 2015a). These fiscal expenditures, however, disregard the indirect economic costs of subsidy regimes. As they incentivize overconsumption of fossil fuels, apart from external costs subsidy regimes entail opportunity costs and market inefficiencies (D. Coady et al. 2015). For example, large public subsidy payments necessitate expensive higher public debt and higher potentially distorting tax burdens. Moreover, they crowd out other productive public spending, for example on health, education, or infrastructure, and make budgets more vulnerable to volatile international energy prices (D. Coady et al. 2015). Davis (2016) estimates global 2014 subsidy payments to result in economic distortion, i.e. a deadweight loss, of about US$ 26 billion.[4] Together with the aforementioned external social costs, total economic costs arise to about US$ 70 billion in 2014 (Davis 2016).

Carbon pricing, on the contrary, can provide an efficient source of public revenue. A price on carbon can be implemented either through taxes (price controls) or certificate trading schemes (quantity controls) which compare in cost-efficiency depending on the slopes of marginal cost and damage curves (Weitzman 1974; L. H. Goulder and Parry 2008; L. Goulder and Pizer 2006). Taxation of fossil fuels according to their carbon content is understood as an efficient source of revenue because taxes on fixed factors of production, such as fossil fuels and other natural resources, entail little or no macro-economic distortions (Ramsey 1927). Furthermore, upstream carbon taxes which are levied directly on the suppliers of fossil fuels are almost impossible to circumvent by market participants. Markandya, González-Eguino, and Escapa (2013) found that by broadening the tax base a carbon price can even increase the overall effi-

[3] The subsidies considered in this paper are what is referred to as pre-tax subsidies which result in consumer energy prices to be below the supply cost of energy. Subsidy payments are calculated as difference between the supply cost and actual consumer price. Post-tax subsidies, in contrast, result in consumer energy prices to be below the supply cost *plus* an appropriate Pigouvian tax accounting for the external costs of energy consumption. Subsidy payments are calculated as the difference between the supply cost plus the efficient tax rate and the actual consumer price (c.f. Coady et al. 2015; Clements et al. (2013); Pigou 1920).

[4] For the year 2012, (Davis 2014) calculates a larger deadweight loss of US$ 44 billion, due to higher oil prices.

ciency of the tax system. This is especially true in economies with a large informal sector which is affected by an upstream carbon tax, but would otherwise not be subject to taxation.

Despite of the described direct and indirect economic, social and environmental benefits of carbon pricing reforms, well-targeted revenue spending is indispensable to ensure that the resulting increase in energy prices will not slow economic growth and poverty alleviation (O. Edenhofer 2015; Jakob and Steckel 2014). Investing all revenues and savings in the provision of basic infrastructure is expected to serve this goal and, thereby, increase public acceptance. Independent of actual distributional and economic effects, public acceptance can be drastically enhanced by earmarking reform revenues, i.e. linking them to defined increases in public expenditures, as the full social gain from fossil fuel subsidy reform may not be obvious to the public (Gevrek and Uyduranoglu 2015; Arze del Granado et al. 2012; Sælen and Kallbekken 2011). Furthermore, the build-up of physical capital and infrastructure has been found to play a crucial role in industrialization and economic performance (Jakob et al. (forthcoming); Jakob and Steckel 2014). In a comprehensive review of empirical and theoretical literature, (Calderón and Servén 2014) find strong consent regarding the positive effect of infrastructure development and income growth. For example, (Aker and Mbiti 2010) highlight that the distribution of mobile phones grants widespread access to information and, thereby, enhances coordination and market efficiency. According to economic theory, especially in an economy like Nigeria where the public budget is predominantly funded by abundant, but exhaustible resource rents, the build-up of physical capital stock is important to substitute for the foregone natural capital and secure long-term development prospects (Arrow et al. 2004; Hamilton and Clemens 1999).

The expansion of public infrastructure has, furthermore, been recognized to be a prerequisite for human well-being and human development which is understood as creating the capabilities for individuals to achieve their personal objectives (Drèze and Sen 2013). A quite extensive body of literature sheds light on different mechanisms through which infrastructure provision fosters human development, e.g. through wage or employment as well as time savings effects or through improved access to education and health, and finds positive connections (Calderón and Servén 2014). While universal access to drinking water, sanitation, clean energy and information is not a sufficient condition, it has been identified as a necessity for reaching the Sustainable Development Goals (SDGs), i.e. achieving poverty alleviation and the protection of the Earth's life support system simultaneously (Griggs et al. 2013). Accordingly, a recent United Nations report (UNTT 2015) estimates sectoral investment needs for achieving the SDGs and finds infrastructure development to constitute the largest share, with globally crudely between US$ 900 and 9,000 billion annually. Finally and most importantly, closing infrastructure access gaps is hoped to compensate the potentially regressive welfare impact of a carbon pricing reform, be it subsidy removal or carbon taxation. Infrastructure provision is hoped to benefit poorer parts of society relatively more because they are more likely to lack access. However, information on access share by income groups is yet too limited to draw thorough conclusions concerning the impact of infrastructure provision on inequality (Calderón and Servén 2014, 21). Despite of these positive effects of infrastructure development, particularly in developing countries with little access to capital markets and potentially instable institutions, the stock of public infrastructure is below a socially desirable level (Jakob et al. (forthcoming)).

In conclusion, the analyzed policy measures can be expected to be environmentally, economically and socially beneficial as carbon pricing incentivizes GHG abatement and more efficient economic practices while infrastructure expansion supports economic growth and reduces social inequalities. Furthermore, the policy mix promises to be institutionally, politically and financially feasible (c.f. Jakob et al. 2014) because upstream carbon taxes are relatively easy to implement and earmarking carbon revenues raises public acceptance and provides the finances for infrastructure development.

2.3. State of the Art: Distribution of Income Impacts and Nigeria

This paper contributes to the scientific debate by systematically analyzing the actual distributional impacts, first, of comprehensive carbon taxation, second, of subsidy removal and, third, of closing infrastructure access gaps across income groups in developing countries, based on the example of Nigeria. After all, the most common argument of opponents of carbon taxation is that poorer segments of society spend a larger share of their income on fuel and energy-intensive goods and are, therefore, more vulnerable to energy price increases (Gevrek and Uyduranoglu 2015; Sælen and Kallbekken 2011). The distributional effect of infrastructure provision has found little attention. The study, thus, combines three strands of literature and contributes to previous case studies on Nigeria:

First, the estimation of consumption-based carbon emissions and respective tax payments by income group contributes to the literature on carbon footprinting and economy-wide carbon taxation. These analyses take into account both direct impacts from fossil fuel combustion and indirect impacts from carbon embodied in consumed goods and services.[5] In developed countries distributional effects of comprehensive carbon taxes have been studied abundantly. Consensus prevails that tax effects tend to be regressive in high income countries: Combining household expenditure with input-output (IO) data, (Wier et al. 2005) find that the CO_2 tax in Denmark is overall regressive, while the direct impact is more regressive than the indirect. Using the same method, Kerkhof et al. (2008) compare a CO_2-only with a GHG tax in the Netherlands and also find regressivity of both taxes. Using the same method, Feng et al. (2010) conclude the same for the United Kingdom. Also for the United States, based on the described method Grainger and Kolstad (2010) conclude that a CO_2 tax would disproportionally burden the poor based on annual income and that this effect is even more distinct when accounting for household size. Rausch et al. (2010), however, who use a Computer-based General Equilibrium (CGE) model analyze the effects of carbon pricing through cap-and-trade and find slight progressivity in the US. Several studies using GCE models, namely Beck et al. (2015), Dissou and Siddiqui (2014) and Rausch, Metcalf, and Reilly (2011) using data from British Colombia, Canada and the US, point out that the impact of carbon taxation on inequality through changes in commodity prices alone may be misleading, highlighting the impact of changes in factor prices and respectively in households' income.

Comparable studies for developing countries cluster around the larger developing countries China, India, South Africa and Indonesia. Their conclusions are less homogenous, but point toward a progressive effect of carbon taxation in developing countries: One of the first studies on this issue referring extensively to developing countries is the case study of Pakistan by Shah and Larsen (1992). Based on a partial equilibrium model, they conclude that in low-income countries carbon taxes are not likely to have such a negative distributional effect as in developed countries. Van Heerden et al. (2005) use a static CGE for South Africa to estimate the distribution of welfare impacts from a carbon tax when revenues are recycled into food tax reductions. For this policy combination they find positive effects for poorer parts of society. Devarajan et al. (2011), however, determine a comprehensive carbon tax in South Africa to have relatively small, but regressive welfare impacts, mostly due to water and energy consumption. Based on household expenditure and carbon intensity data, Brenner, Riddle, and Boyce (2007) find the introduction of carbon charges to be progressive in China, with rich households consuming disproportionally more carbon intensive goods. They highlight that

[5] Refer to Appendix A for an overview table of the literature on the direct and indirect distributional impacts of carbon pricing which is discussed in this section.

their finding is strongly driven by differences between rural and urban households because urban households are typically wealthier and exhibit more carbon intensive expenditure patterns. Datta (2010) establishes a partial equilibrium framework to analyze charges on separate fossil fuels in India and finds all fuel taxes except the one on kerosene to have neutral or progressive impacts on income distribution. The study highlights that kerosene is used for cooking and lighting by poorer households who might be incentivized to switch to more carbon-intensive biomass if kerosene prices were raised (c.f. also IPCC (2011)). Estimating the overall economic impact of carbon pricing in Indonesia based on a static CGE, Yusuf (2008) and Yusuf and Resosudarmo (2012) conclude that a carbon tax or specific fuel price increases would be robustly progressive in rural and neutral or slightly progressive in urban areas, finding rural households to be less sensitive to prices of energy-related commodities. Finally, Arze del Granado, Coady, and Gillingham (2012) provide a meta-analysis of previous studies undertaken in twenty developing countries in Africa, Asia, the Middle East, and Latin America[6] of which most are based on household expenditure data in combination with input-output tables. The analysis concludes that overall the total, i.e. direct and indirect, welfare impact of increased fuel prices is approximately neutrally distributed. They find that the indirect impact makes up as much as 60 percent in African countries of the total impact, indicating that a large portion of fuel consumption is for intermediate use. Also, they highlight that while the distribution of the direct impact is overall progressive, this finding hides differences among fuels, such as the progressivity of gasoline and electricity and the regressivity of kerosene price increases.

Notably, based on this rather comprehensive review of studies analyzing the distribution of total, i.e. direct and indirect, consumption-based welfare impacts of carbon taxes (summarized in Appendix A), there seems to be a slight methodological divide in the literature: While high-income country studies often rely on household expenditure data coupled with input-output tables, respective developing country studies are mostly based on equilibrium models.[7] Common conclusions drawn in the papers are that poorer segments of society in developing countries consume disproportionally less carbon-intensive goods, resulting in predominant progressivity of carbon pricing reforms. Furthermore, urban and rural households exhibit differ-

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[6] Cameroon, Gabon, Central African Republic, Senegal, Ghana, Mali, Congo, Burkina, Madagascar, Bolivia, Peru, Honduras, Bangladesh, Sri Lanka, Cambodia, India, Indonesia, Jordan, Lebanon; mainly (D. P. Coady et al. 2006; Bacon, Bhattacharya, and Kojima 2010)

[7] Additionally, Seriño and Klasen (2015) use IO and household data to calculate consumption-based carbon footprints for households of different income groups in the Philippines. However, they do not calculate the relative distribution as share of expenditure.

ent expenditure patterns and differ in average income levels, resulting in a larger average carbon footprint of urban households relative to their (on average higher) total expenditure. Also Datta (2010) and Arze del Granado, Coady, and Gillingham (2012) indicate that price increases of different fuels differ in their distributional effects, a point which is further discussed in the subsequent analysis of literature on fuel-based subsidies and taxes.

Secondly, the calculation of direct impacts from the removal of the kerosene and gasoline subsidies across different income groups in Nigeria adds to fairly comprehensive previous research on fuel-specific energy consumption patterns and distributional impacts of specific fuel prices, including previous case studies on Nigeria. Again, results differ between developed and developing countries, but overall reveal more mixed findings regarding the distributional impact. A recent study by the Organization for Economic Cooperation and Development (OECD) (Thomas and Flues 2015) provides a comprehensive analysis of distributional effects of transport, heating and electricity taxes in 21 OECD countries[8], based on a microsimulation model. While the study emphasizes the heterogeneity of results across countries, the unweighted averages of all countries point towards proportional or slightly progressive taxes on transport fuels, slightly regressive taxes on heating fuels and clearly regressive electricity taxes. In comparison, based on household budget surveys, Sterner (2012b) analyzes transport fuel taxation in seven European countries and finds regressivity in most of the countries, emphasizing however that overall welfare impacts are so small that they are practically neutral. Sterner (2012a) includes three chapters which analyze fuel tax distribution in the United States, two using expenditure and input-output data, the third using an economic multi-market model for vehicles. They all find taxes to be regressive while the magnitude of this distributional impact might depend on the method and could be easily compensated through redistributive revenue recycling.

Among developing countries direct distributional effects are similarly mixed, mostly however, referring to subsidies instead of taxes. Bacon, Bhattacharya, and Kojima (2010) analyze fuel-specific consumption patterns by income quintiles in nine developing countries in Africa and Asia,[9] based on household expenditure survey data. Again heterogeneity in specific fuel consumption patterns across countries as well as between rural and urban areas is large. While liquefied petroleum gas, gasoline and diesel subsidies show strong average regressive impacts

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[8] Austria, Belgium, Chile, the Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Poland, the Slovak Republic, Slovenia, Spain, Switzerland, Turkey and the United Kingdom

[9] Bangladesh, Cambodia, India, Indonesia, Kenya, Pakistan, Thailand, Uganda and Vietnam

in all countries, entailing almost no benefit to the poor, kerosene subsidies are progressive in three, neutral in two and regressive in four of the nine countries. Bacon, Bhattacharya, and Kojima (2010) explain the regressivity even of kerosene which is normally thought of as lighting and cooking fuel of the poor by its near perfect substitutability with diesel. Therefore, when subsidized kerosene prices are cheaper than diesel, the former is almost universally diverted to the transport sector, benefiting higher-income households and businesses. Rao (2012) equally finds regressivity of a kerosene subsidy in the state of Maharashtra in India, highlighting that it has minimal financial value for poor households in rural areas, while effects in urban areas were progressive. The study emphasizes that only a small share of total subsidy value reaches the households as it is partially diverted as rents along the supply chain or lost to the black market, making the subsidy a very inefficient and expensive instrument for redistribution irrespective of its distributional effect. Finally, Sterner (2012a) provides analyses of a dozen developing and emerging countries[10], mostly combining expenditure with input-output data. Sterner (2012a) and Sterner (2012b) mainly conclude that in the case of transport fuels, both in developed as well as developing countries, tax progressivity tends to decline with higher country income levels. In low-income countries, private transport and respective fuels tend to be luxury goods and are largely consumed by the rich.

For Nigeria, one previous study provides a crude assessment of the distribution of direct impacts of subsidy removal on households (Umar and Umar 2013). Also based on household survey data, Umar and Umar (2013) divide households in three income groups, comprising the lowest and middle 40 percent and the top 20 percent of households. Averaged across all households, they find that a 53 percent increase in liter fuel price might decrease household income by 3.8 percent.[11] While the paper does not separately list relative impacts on income for each group, its conclusion seems to be that due to higher shares of direct fuel consumption, richer households receive higher subsidy payments relative to income. This finding is in line with Soile and Mu (2015) who investigate the distribution of direct impacts from the subsidy regime in Nigeria, calculating Gini coefficients and Lorenz concentration curves based on household expenditure data. Relative to income, they find a neutral distribution of kerosene subsidy payments and strong regressivity of petrol subsidy payments. Siddig et al. (2014) analyze the implications from reduced fuel subsidies on the Nigerian economy as well

[10] among others Chile, China, Costa Rica, Ethiopia, Ghana, Iran, India, Kenya, Mexico, Peru, South Africa, Tanzania

[11] (Umar and Umar 2013) do not specify how they arrive at the assumption of a 53 percent fuel price increase.

as on poor households, taking into account effects from direct and indirect price changes as well as changes in factor prices. In order to study distributional implications, an applied CGE is combined with data for 12 types of household from a Nigerian social accounting matrix. Siddig et al.(2014) conclude that even though richer households are more affected in relative terms, in terms of real and factor income a subsidy removal entails negative effects for all households for which especially poor rural households need to be compensated. Furthermore, Nwachukwu and Chike (2011) investigate price elasticity of demand due to fuel subsidy changes in Nigeria, finding high demand elasticities and respective subsidy-induced overconsumption. However, they merely analyze patterns of fuel consumption for private vehicles in four of the largest Nigerian cities so that their sample is limited to presumably rich and more price elastic segments of society. Further case studies focus on Nigeria's energy system and inadequate supply, but do not draw detailed conclusions concerning distribution: Ogwumike and Ozughalu (2015) investigate the level and determinants of energy poverty in Nigeria, based on 2004 household data, and find at least 75 percent of population to suffer from energy poverty, mostly due to inferior energy sources like firewood. Analyzing options for sustainable development of Nigeria's energy system, Oyedepo (2014) concludes that measures to enhance energy efficiency and the deployment of decentralized renewable sources are most promising to improve Nigeria's inadequate and irregular energy supply.

Takeaways from previous fuel-specific analyses are that the distribution of income effects differs by fuel and depends on the country-specific context. However, in developing countries, there is a tendency for subsidies on various fuels to be distributed regressively which is also assumed to be the case in Nigeria. Furthermore, irrespective of the distributional effect, in total the major portion of subsidy payments is tabbed by richer segments of society due to their overall higher consumption levels or lost to market inefficiencies. These findings suggest that subsidies are a very expensive and inefficient instrument for poverty and inequality alleviation.

Third, the literature concerning infrastructure provision and inequality is rather dispersed. As mentioned above, largely, studies on the micro-level impact of infrastructure development focus on the mechanisms through which infrastructure provision fosters human development, for example through improvement of skills, health and information access (Calderón and Servén 2014). Concerning the relationship between public spending and distributional outcomes, Chatterjee and Turnovsky (2012) model how public growth policies affect inequality dependent on the source of public finance. However, this study does not take stock of the actual initial access distribution. Empirical studies which decidedly analyze the actual distribution of access to basic infrastructure types among households of different income levels in developing countries do to the best of knowledge not exist. The World Bank research paper on the income distribution and growth effects of infrastructure by Calderón and Servén (2014, 21) concludes that due to scarce research, "the limited information available on access and affordability for households at different percentiles of the income distribution represents a major obstacle to progress in establishing the consequences of infrastructure development for inequality and, therefore, its overall contribution to poverty reduction."

This paper adds to previous research methodologically and with regards to content: Using high resolution expenditure data combined with input-output tables, this study provides a detailed analysis of total per capita carbon footprints, stemming from direct fuel use as well as carbon embodied in consumption goods. Based on these results, the paper provides an additional developing country analysis of distributional impacts of comprehensive carbon taxation which is based on the described method instead of modelling; also it is the first one to analyze the distribution of both a tax and subsidy removal in Nigeria, expanding related evidence by insights from Africa's largest economy. Furthermore, infrastructure access is determined on per capita level, arriving at a precise estimate of investment needs for providing full access which adds not least to previous cruder estimates of SDG finance needs. Finally, this study is the first to compare overall carbon tax revenues with total infrastructure investment needs on national level, both in total as well as in distributional terms.

3. Background Nigeria

With a nominal GDP of US$ 657 billion in 2015 and a population of over 170 million, Nigeria is the largest economy and most populous nation in Africa (World Bank 2016b). The federal government's long-term strategy for economic development, Vision 20:2020 (FGN 2010), envisages to position Nigeria among the world's 20 largest economies by 2020, with a GDP growth target of US$ 900 billion. Rapid expansion and diversification in the private non-oil sectors is expected to be the main driver of socio-economic transformation and employment creation in order to achieve declining economic and fiscal importance of the mining sector in relative terms. The Vision and the 2011-2015 Transformation Agenda (FGN 2011) call for significant investment in basic physical infrastructure, with a focus on electricity generation and distribution. Also, they call for reforms to shift investment to increase private-sector activities and productivity of human capital as well as for anti-corruption and good governance measures. The respective expansion of energy access, road transport, petroleum refining capacities, but also higher standards of living of a growing population, e.g. by private car ownership, could imply more than a doubling of greenhouse gas (GHG) emissions by 2035 in a business-as-usual (BAU) scenario (FME 2015; Cervigni, Rogers, and Henrion 2013, 1).[12] To forego large negative environment and climate impacts and a lock-in of high future emissions through the construction of carbon-intensive infrastructure, it is crucial to take early steps toward sustainable development in Nigeria. In this spirit, the government intends a 20 percent emission reduction below the BAU scenario, or 45 percent with international financial and technical support, by 2030 (FME 2015; Buhari H.E. 2015).

In order to meet these envisaged sustainable human and economic development goals, large social, economic, and fiscal challenges have to be overcome: First, high social inequality and low human capacities, second, the economic dependency from the petroleum sector as well as, third, the fiscally expensive fossil fuel subsidy regime and large wage bills from public sector employment. In order to tackle those challenges, in recent years the Nigerian government pursued reform efforts which are broadly in line with the policy measures analyzed in this paper: First, the government partially reformed the fossil fuel subsidy regime, second, it broadened the tax collection and improved fiscal consolidation and, third, it identified the provision of efficient infrastructure as highest priority sector for public investments. This chapter introduces the remaining challenges before outlining the three recent reform efforts and how they align with the policy instruments analyzed in this paper.

Social Challenges

The Nigerian government is facing fundamental shortcomings in the country's human development and good governance practices. In 2015 peaceful and transparent elections were held which were deemed largely free and fair by international and regional observers (CIA 2016). Despite of rather stable political conditions and robust economic growth, social inequalities increased throughout the past decade, both between rural and urban areas as well as between Nigeria's six geopolitical regions (Barungi, Ogunleye, and Zamba 2015). The World Bank classifies Nigeria as lower middle-income country and 53 percent of the population lived below the poverty line of US$ 1.90 a day in 2009 (World Bank 2016b). With its Human Devel-

[12] In its business-as-usual GHG emissions scenario, the Federal Ministry of Environment expects a 114 percent increase of emissions between 2015 and 2030, assuming an annual economic growth of 5 percent, population growth of 2.5 percent, universal (on-grid and off-grid) electricity access and supply as well as a tripling of industrial activity until 2030 (FME 2015).

opment Index ranking 152nd globally in 2014, it remains a low human development country (UNDP 2016). Furthermore, recent insurgency by the militant group Boko Haram poses a serious security threat and caused a humanitarian crisis in the north-eastern region, internally displacing 2 million individuals since 2013 (IOM 2015). Generally, the government has been struggling to improve low levels of institutional and human capacities, regulatory inefficiencies and high levels of corruption (CPI 2016; IMF 2013b).

Economic Challenges

Apart from meeting social challenges, Nigeria is struggling for macro-economic consolidation. Nigeria is Africa's largest oil producer, seventh largest in the Organization of the Petroleum Exporting Countries (OPEC), and was the world's fourth largest exporter of liquefied natural gas in 2012. Large remaining reserves guarantee another 50 years of extraction (GIZ 2015). Throughout the past decade, the Nigerian economy grew steadily between 5 percent and 7 percent annually (Barungi, Ogunleye, and Zamba 2015). Importantly, in recent years, the non-oil sector was the main driver of GDP growth, with services contributing around 57 percent, manufacturing 9 percent and agriculture 21 percent of GDP in 2013. Between 2009 and 2013 the mining and quarry sector (including oil and gas) declined in relative economic importance from 30 percent to 13 percent of GDP. Despite of increasing economic diversification, however, oil revenues still accounted for 90 percent of total export earnings and for over 70 percent of government income, making fiscal consolidation highly vulnerable to volatile global oil prices. The public budget is further tightened as oil production falls below expected rates due to extensive oil theft and pipeline sabotage, while in the gas sector the shortfall of adequate infrastructure restricts the monetization of large amounts of - presently flared - gas (IISD 2012; GIZ 2015). Oil price volatility also affects the domestic economy because despite of extensive crude oil exports about 85 percent of domestic demand for refined petroleum products is supplied by imports. Due to poor maintenance and mismanagement only 30 percent of the capacity of domestic refineries is used (GIZ 2015).

Fiscal Challenges

Apart from decreasing oil revenues and poor public spending practices (IMF 2013b), two large fixed public expenditure items crowd out investment in critical public services in Nigeria: First, one of the main fiscal stressors and reason for high budget deficits is the existing subsidy regime which is also subject to global oil price changes (FMF 2011). Established in the 1960s, the system administratively sets fixed kerosene and petrol prices. The Petroleum Support Fund (PSF) was established to finance the difference when imported parity prices are higher than the fixed price levels and to collect the revenues when import prices are lower (IMF 2013). However, due to high oil prices since 2009 the PSF hardly received payments, while subsidy costs rose to 4.7 percent of GDP in 2011 (IMF 2013). While only US$ 1.7 billion had been appropriated in the 2011 budget, actual payments totaled at US$ 5.3 billion (FMF 2012). While this budget gap is mostly due to the unpredictable nature of volatile global oil prices, the subsidized price difference has also encouraged widespread smuggling to neighboring countries and other fraud, like inflated consumption figures and landing costs (IISD 2012; Whitley and van der Burg 2015). For example, US$ 1.6 billion of subsidy paid to marketers in 2011 were not supplied. While 59 million liters of fuel a day were subsidized, only 35 million liters a day were actually consumed in Nigeria in 2011 (Siddig et al. 2014).

Second, apart from the subsidy regime, another main fixed expenditure item and reason for large budget deficits is the large wage bill (FMF 2011). In the 2013 budget, personnel costs accounted for more than a third of total spending (FMF 2015). Despite of increasing economic diversification, the public sector is still the largest employer of formal labor in Nigeria. While the rate of unemployment reached 9.9 percent in the third quarter of 2015 (Ventures Africa 2015), private sector development faces major challenges. The existing gap of, in particular physical, infrastructure has been identified as a main obstacle (World Bank 2016a; FMF 2015; FMF 2011). Especially, the supply of energy is insufficient and unreliable which causes large costs to private businesses (Aliyu, Ramli, and Saleh 2013). Due to the low level of on-grid electrification as well as frequent blackouts, the majority of Nigerian businesses and households relies on alternate power sources, to the largest part solid biomass and fuel generators (see Excursus: The Role of Firewood and Household Energy Consumption). In 2013 about 80 percent of the population was experiencing poor power supply and 85 percent of Nigerian businesses and manufacturers rely on private fuel generators, spending on average NGN 3.5 trillion (US$ 23.5 billion) per year on their operation and maintenance (GIZ 2015; Aliyu, Ramli, and Saleh 2013). Overall in 2011 60 million private power generators were in operation, which is one for every 2.5 individuals (GIZ 2015).

Excursus: The Role of Firewood and Household Energy Consumption

Solid biofuels accounted for over 80 percent of Nigeria's energy consumption in 2013, of which 7 percent was used by industry and over 90 percent were used by households. Furthermore, the residential sector accounted for over 80 percent of final energy demand in Nigeria in 2013 (IEA 2015b). GIZ (2015) estimates the average per capita consumption of fuel wood to be 2.5 m^3 annually. Predominantly, firewood is burned for cooking purposes as more than 65 percent of households rely on it as their main cooking fuel (own calculation based on NBS 2011), mostly using open fires which have very low thermal efficiency and result in high indoor air pollution (Ogwumike and Ozughalu 2015). Especially in view of Nigeria's fast growing population, expected to be the world's third most populous country in 2050 with around 440 million inhabitants (PRB 2013), such energy consumption practices can entail large negative impacts on the environment and health. Importantly, over 90 percent of used firewood is acquired without purchase so that market-based regulation, e.g. through a tax, is impossible (own calculation based on NBS 2011). Per capita firewood use is especially high in rural areas and first rises, then declines with rising income (Fig. 1). In order to induce reduced use of firewood, it is necessary to provide universal adequate and affordable access to modern environmentally-friendly sources of energy (Ogwumike, Ozughalu, and Abiona 2014).

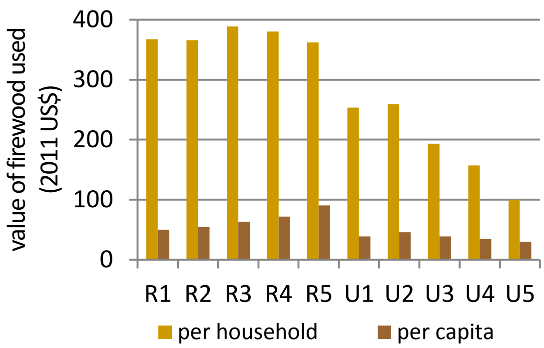

Fig. 1: Value of used firewood, in 2011 US$ per household and capita, in Nigeria in 2011.
Source: own calculation based on NBS (2011)

Reform Efforts

Drawing conclusions from these diverse challenges, in recent budget reports and medium-term expenditure frameworks the Nigerian government has acknowledged political reforms which could serve as legislative framework for the policy mix analyzed in this paper (FMF 2012; FMF 2015): First, the partial reform of the subsidy system, second, the broadening and reform of the tax system and, third, the prioritization of public infrastructure investments.

First, in recent years the Nigerian government launched several attempts to reform the subsidy regime. On 1 January 2012 the petrol price was fully deregulated while the pegged kerosene price of NGN 50 (US$ 0.34) per liter stayed unchanged. Consequently, the liter price of petrol rose by 117 percent, from the previously fixed NGN 65 (US$ 0.44) to the global spot price of

NGN 141 (Whitley and van der Burg 2015). Preceding the reform, the government launched a campaign for the Subsidy Reinvestment and Empowerment Program (SURE-P) to mitigate the impact of removing the subsidy on the poor. The Program promoted pro-poor investments in human capital and public infrastructure development, including road and railway networks, mass transit, as well as health and education facilities and vocational training (IMF 2013a). Despite the initiative, public opposition to the subsidy removal was extensive and prompt (Akinyemi et al. 2014). A national strike launched by two large trade union federations resulted in violence and a near state of emergency, prompting the president to announce on 15 January that the reform would partially be reversed, fixing a new petrol price at NGN 97 (US$ 0.65) (IMF 2013a). Preceding the elections in 2015, the Petroleum Ministry reduced the petrol price again to NGN 87, supposedly due to the reduction in international crude oil prices (Premium Times Nigeria 2015). Finally, in January 2016, the new government abolished the PSF and reformed both subsidies. The petrol price was fully deregulated and fell to the import price of NGN 85 per liter. The kerosene subsidy is planned to be continued at least until 2017. However, the pegged price was increased to NGN 83 per liter which is above the kerosene import price at January 2016 oil prices (FMF 2015; Bloomberg 2015).

Second, the Nigerian government is actively exploring alternative sources of revenue, focusing on broadening the tax system, in order to achieve fiscal consolidation and to return to a fiscal deficit below 3 percent of GDP, instead of 20 percent of GDP in 2012 (IMF 2013b, 20; FMF 2011, 8). Budget consolidation is especially challenging in the face of currently low oil prices and respectively low revenues. Reform efforts focus on measures to increase revenues from the non-oil sector and higher income groups while reducing the tax burden for private businesses (Barungi, Ogunleye, and Zamba 2015). The 2015-17 Medium Term Expenditure Framework introduces a surcharge on luxury goods and cuts in recurrent payments. While not explicitly referring to carbon taxation, Nigeria's INDC mentions fiscal reform as efficient tool in the context of climate mitigation. Furthermore, the INDC states that fiscal reform "releases significant resources in the budget that can fund investments in efficient infrastructure and other fiscal policies, thus creating jobs and fueling growth" (FME 2015, 9). On international level under the UNFCCC, the Nigerian government also calls for transparent and accessible financial resources from developed countries to support mitigation and adaptation activities in developing countries and to ensure equitable access to sustainable development (Buhari H.E. 2015).

Third, in recent expenditure frameworks and policy strategies, the provision of basic physical infrastructure has been identified as highest priority in public spending (FMF 2011; FGN 2011; FMF 2012; FMF 2015). In the 2011 budget, the majority of capital expenditures, 43 percent, was devoted to closing the existing infrastructure gap, recognizing that "poor infrastructure has for long been an impediment to the growth of the non-oil sector" (FMF 2012, 57). Between 2015 and 2017, US$ 2 billion of public funds are devoted to infrastructure development and rehabilitation (Barungi, Ogunleye, and Zamba 2015). Emphasis is placed on power, transport, oil and gas infrastructure as well as on housing and water resources (FMF 2015). Specifically, the Nigerian government plans to achieve an electrification rate of 75 percent and triple the transmission capacity by 2025 (FGN 2010). Current energy supply is irregular and inadequate to meet the high and rising energy demand (Oyedepo 2014; Aliyu, Ramli, and Saleh 2013; Olaseni and Alade 2012). Cervigni, Rogers, and Henrion (2013) estimate that in order to sustain the aspired high pace of growth, until 2030 electricity generation would have to increase by a factor of 9. Importantly, the power and petroleum sector have the highest GHG emission reduction potentials (FME 2015). Efficiency improvements, such as efficient lighting (both on-grid and off-grid), fuel efficiency and halting gas flaring, as well as expansion of renewables, such as off-grid solar and hydro power, are expected to yield large emission reductions at negative cost, i.e. resulting in economic gains in Nigeria (FME 2010; Oyedepo 2014; Cervigni, Rogers, and Henrion 2013). The 2012-2017 Multi-Year Tariff Order specifies concrete feed-in tariff rates for onshore wind, solar, small hydro and biomass energy. Furthermore, the 2011 Renewable Energy Plan intends to increase the share of renewable electricity generation capacity from 13 percent in 2015 to 36 percent in 2030 to meet Nigeria's growing demand. Finally, an early-2016 tariff order obliges electricity distribution companies to source at least 50 percent of their procurement from renewables (IEA 2016). Without those and further political intervention, generation capacity from gas is expected to grow most in terms of total capacity and capacity from coal will be added to the mix (GIZ 2015).

Concluding from this overview, large human and economic development challenges remain to be solved in Nigeria. Furthermore, increasing GHG emissions due to high economic and population growth rates entail great climate change mitigation potential. In recent years, the Nigerian government has launched political reforms which are compatible with the policy mix analyzed in this paper, namely carbon pricing reform and infrastructure development. Also particularly in the energy sector first policy initiatives lead the way to clean, sustainable development. However, to achieve low-carbon and socially inclusive development further political guidance and more efficient implementation of currently broadly framed policy strategies are indispensable.

4. Data

Data on household consumption expenditures in Nigeria are taken from a 2010/2011 general household survey conducted jointly by the Nigerian National Bureau of Statistics (NBS) and the Living Standards Measurement Study (LSMS) Program of the World Bank (NBS 2011). The survey is carried out biannually every two years, comprising a randomly selected representative sample of 5,000 households. Weights for each household allow for the results to be extrapolated to the total Nigerian population. The survey comprises household expenditure data as well as data on the households' socio-demographic characteristics and dwelling attributes.

The household consumption expenditure schedule used for the survey collects information on 170 goods and services with different reference periods of 7 days, one month or 6 months preceding the interview date. The survey collects biannual data during the post-planting (August to October) and post-harvest (February to April) season. In order to estimate total annual expenditures on each item, data from the different reference periods are extrapolated to half a year for each season. Data from both survey rounds are summed to cover the whole year. Qualitative questions in the survey on the type of water source, the type of latrine, the source of electricity, if any, and phone use by households are used to estimate average infrastructure access shares among income groups.

In addition to the detailed raw data of household expenditures, the LSMS survey specially features a separate dataset comprising aggregate per capita and household expenditure data which are temporally and regionally deflated and, therefore, provide a robust basis for the division of households into income groups. As a basis for the subsequent analysis of distributional effects, ten income groups are formed, dividing Nigerian households into rural and urban areas as well as income quintiles. The division in rural and urban parts of the population prevents blurring potential general differences in socio-economic characteristics as well as energy use and consumption patterns. Households are then divided into weighted quintiles based on their average aggregate annual per capita expenditures. Consistent with most studies using household data annual per capita expenditures are used as proxy for income levels (c.f. Kerkhof, Nonhebel, and Moll 2009; Feng et al. 2010).

	min	max	mean	size	pop share
R1	125	641	494	7	15.80%
R2	641	878	760	7	14.52%
R3	880	1,175	1,012	6	13.10%
R4	1,176	1,675	1,393	5	11.38%
R5	1,675	10,421	2,639	4	8.55%
U1	212	1,030	782	6	9.51%
U2	1,034	1,484	1,267	6	8.31%
U3	1,484	2,006	1,735	5	7.34%
U4	2,008	2,757	2,356	5	6.60%
U5	2,769	16,776	4,127	3	4.88%

Tab. 1: Annual per capita income in PPP-adjusted 2011 US$ (minimum, maximum and mean), average household size and percentage share of total population, by rural (R1-5) and urban (U1-5) household quintiles. Note: income levels increase with increasing numbers R/U 1 to 5.

The distribution of average per capita income and household size across the ten income groups, shown in Tab. 1, indeed exhibits general socio-economic differences between rural and urban households. On average, rural households are less wealthy. The minimum capita income in the highest rural quintile R5 is approximately level with the mean income of the third urban quintile U3 and the mean of the second rural group R2 is still smaller than that of the bottom urban quintile U1. The large income interval in both the rural and urban richest quintiles, R5 and U5, indicates the existence of a small super-rich upper class in Nigeria. Furthermore, rural households are on average larger in capita size than urban households, ranging from 7 to 4 (R1-5) and 6 to 3 (U1-5) respectively. Notably, while quintiles in both groups hold equal numbers of households, the distribution of household sizes among quintiles entails that on per capita basis the lower quintiles are much larger and represent a greater share of the total population (c.f. column 'pop share').[13] Overall rural quintiles capture 63 percent[14], urban only 37 percent of the population.

Further modification of the dataset was necessary due to incomplete or inaccurate observations: Observations were completely excluded only when households could not be attributed to an income group (due to missing aggregate expenditure or rural-urban data), but not when

[13] The LSMS survey is carried out on a household basis - with the smallest unit of observation being households, so that the level of detail in the collected information does not allow for dividing the population in capita-based quintiles.

[14] The World Bank finds a slightly smaller percentage of rural population in 2011 of 56 percent (World Bank 2016b) while Siddig et al. (2014) list 70 percent of rural population.

single values on expense items were missing. As all analyses in this study are averaged over the income groups, single missing observations are not expected to distort the results, as long as they are carefully excluded from drawing the averages. Outliers were detected as values larger than the largest 0.01 percentile of each variable and replaced by the mean of the income group of the affected household and variable. Finally, around 4,800 household observations were used in the analysis.

Information on carbon intensities of each sector are calculated for the year 2011 based on the environmentally-extended multi-regional input-output (MRIO) tables provided by the Global Trade Analysis Project (GTAP 9; Narayanan et al. 2015) which traces the interdependencies of 57 sectors in 140 regions globally. For each sector, the model allows to trace the average tons of CO_2 emissions per 2011 US$ of all its products, taking account of the energy commodities and inputs used in the production.[15] The purchasing power parity conversion factor for 2011 provided by the World Bank is used to convert carbon intensities from tCO_2 per US$ to tCO_2 per NGN in order to make them compatible with Nigerian expenditure survey data. Based on this information, the respective carbon-tax-induced price changes and impacts of a fossil fuel subsidy reform can be calculated for all 57 sectors.

GTAP Sectors (9.0, 2011)		Household Consumption Items (NBS, 2011)	Household Carbon Footprint per Category
- Paddy rice - Electricity - Transport - …	Matching and multiplying 28 sectors ⟷ 150 items	- Rice - Maize - Electricity - …	- CO_2 Rice - CO_2 Maize - CO_2 Public transport - CO_2…
57 sectors **Carbon intensity** (tCO_2/ NGN)		170 consumption items **Household expenditure** (NGN)	CF from 150 consumed items **Household Carbon Footprint** (tCO2)

Fig. 1: Matching of Sectors in the MRIO with Disaggregated Household Consumption Items from the Household Survey

Finally, household expenditure data are matched with the carbon intensity MRIO data, i.e. all 170 disaggregated consumption items covered in the household survey are assigned to the corresponding 57 MRIO sectors, following convergence tables provided by GTAP (c.f. Seriño and Klasen 2015). Finally, 150 disaggregated consumption items are matched to 28 GTAP sectors following the procedure depicted in Fig. 1.[16] Some items, mostly services, were not matchable and the remaining 29 sectors' output does not comprise end-consumer products.

[15] The MRIO data do not include non-energy related sources of GHG emissions, such as methane emissions from land use change. The carbon tax referred to in this paper is, therefore, a CO_2 tax.

[16] For full matching table of household consumption items and GTAP sectors see Appendix B.

Therefore, these sectors are not directly included, even though implicitly their carbon-intensity is taken into account as inputs to the other sectors.

5. Method

The overall distributional impact of a carbon pricing reform coupled with closing infrastructure access gaps in Nigeria is estimated in four steps. Total tax revenues and investment needs until 2030 are compared in a fifth step, followed by a comprehensive discussion of methodological limitations: First, the direct and indirect price changes of different product categories after taxation are calculated. The price increases of consumer goods depend on their respective carbon intensities, i.e. carbon contents per monetary unit, which are estimated using an environmentally-extended MRIO analysis. Second, the distribution of the direct and indirect welfare impact of the carbon tax is assessed for households of different income quintiles, based on household survey data. The income impacts depend on the price changes as well as the expenditure shares of each product, averaged per household group. Third, the direct welfare impact of a complete removal of the existing kerosene and petrol subsidies is estimated using the difference between the subsidized domestic price and global retail price per liter for both fuels as well as annual expenditures. Fourth, the per capita cost of granting access to the four types of basic infrastructure is estimated based on different sources and the distribution and total extent of infrastructure access gaps are calculated based on qualitative household survey data. Sixth, total tax revenues until 2030 are calculated for three different tax rates and compared to total infrastructure costs for a margin of cost assumptions in a sensitivity analysis. Finally, methodological limitations of all calculations are discussed comprehensively.[17]

5.1. Direct and Indirect Price Changes

When a comprehensive carbon tax is imposed on commodities in Nigeria, prices of consumer products will change. In the short-term, these price changes depend mainly on carbon intensities, i.e. the amount of carbon emitted per monetary unit of each product. Carbon emissions can be classified as direct and indirect emissions. Direct emissions originate from the direct consumption of energy, e.g. from fossil fuel combustion for cooking, heating, lighting, and private transport. Respective tax payments are born directly by consumers purchasing the energy commodity. Indirect emissions are generated during the production process and waste treatment of consumed goods and services. Taxes for indirect emissions are imposed on pro-

[17] A digital appendix (described in Appendix D) contains all calculations and raw data underlying this study.

ducers. In accordance with previous studies, it is assumed that producers pass these respective increases in energy production costs fully forward onto the domestic prices of goods and services (Arze del Granado, Coady, and Gillingham 2012; Feng et al. 2010; Kerkhof, Nonhebel, and Moll 2009; Kerkhof et al. 2008; Wier et al. 2005). Therefore, in this study tax payments for both direct and indirect emissions are expected to be borne by the end consumer, even though, in the long-run, producers may partially absorb the price increases due to substitution or efficiency measures. Consequently, the total price change of goods in consumption category or sector k, Δp_k^{tot}, is the sum of direct and indirect price changes:

$$\Delta p_k^{tot} = \Delta p_k^{dir} + \Delta p_k^{ind} \tag{1}$$

where Δp_k^{dir} is the direct price change of product category k and Δp_k^{ind} is the indirect price change of product category k, both in US$ of tax payment per US$ of product value. The price changes of consumption category k are the result of taxation of direct and indirect carbon emissions, as shown in Eq. (2)

$$\Delta p_k^{dir} = e_k^{dir} * t \qquad\qquad \Delta p_k^{ind} = e_k^{ind} * t \tag{2}$$

where e_k^{dir} and e_k^{ind} represent the average direct and indirect carbon emission intensities of product category k, measured in tons of CO_2 emitted per US$ of product value, and t is the tax rate, in US$ per ton of CO_2.

Both direct and indirect carbon intensities, e_k^{dir} and e_k^{ind}, are quantified based on the MRIO. The MRIO analytical framework serves to determine the interdependencies of all sectors in an economy and between economies. Based on information on the production structure of industries, input-output tables present the production of an economy depending on intersectoral relations and final demand. The basic structure of MRIO can be written as follows:

$$X = (I - A)^{-1} * Y \tag{3}$$

where X is the total production output matrix. The $(I - A)^{-1}$ matrix is referred to as the Leontief inverse, (c.f. Leontief 1986), and represents the total production of each sector required to satisfy a particular final demand in the economy. Respectively, A is a matrix of technical coefficients based on intersectoral commodity flows, i.e. connecting the output of each sector to its inputs from other sectors, I is the identity matrix and Y is the vector of final demand.[18] The environmental extension of MRIO allows relating carbon intensities to monetary flows in the input-output tables. For each product category, the model allows to trace the average carbon emissions associated with each monetary unit, taking account of the energy commodities, coal, crude oil, natural gas, petroleum products, electricity, and gas distribution (GTAP 2008), and inputs used in the production. Accordingly, the emission intensities of each product category or sector k are calculated as follows:

$$e_k^{dir/ind} = c(I - A)^{-1} * Y \tag{4}$$

where c is a vector assigning a carbon coefficient to each sector of the economy. The coefficients are a result of several factors, including sectoral fuel consumption, energy conversion coefficients as well as emission factors of commodities, and the ratio of carbon stored as well as the fraction of carbon oxidized of energy commodities (GTAP 2008). Notably, most previous studies use MRIO only for the assessment of indirect price changes of goods and services and calculate direct price changes separately for each fuel type, based on their respective carbon content. In this study, however, this method is not feasible because reliable information on actual domestic retail prices per quantity of fossil resource is not readily available for the Nigerian market which makes it impossible to convert from expenditures to quantities consumed to embodied emissions (IISD 2012). Therefore, the averaged emission intensities of the energy and commodity sectors provided in the MRIO are expected to provide a feasible approximation.

5.2. Carbon Tax: Total Payments and Distribution of Income Impacts

The magnitude of the welfare impacts and their distribution across income groups depend both on the carbon intensity of consumption items as well as on their relative importance within the average consumption basket of each group. The distribution of the welfare impact of a tax is referred to as progressive if the relative welfare loss increases with household income. For example, when higher-income households spend relatively more money on carbon-intensive products, like petrol and electricity, than lower income groups, their tax burden accounts for a higher percentage share in their total income and the tax is progressive (Arze del Granado, Coady, and Gillingham 2012).

[18] For further details on MRIO refer to J.C. Minx et al. (2009).

The amount of tax payments by specific households is a result of the carbon content related price increase of different consumption items as well as the level of expenditure on these items. Accordingly, the total tax payments, *d*, of income group *q* are calculated as:

$$d_q = \sum_k \Delta p_k^{tot} * i_{kq} \tag{5}$$

where Δp_k^{tot} is the total price change of product category *k* and i_{kq} is the total annual expenditure of household group *q* on consumption items in product category *k*. The relative income impact is obtained by dividing this total income impact by the total expenditures of the household. Both results are averaged across each income group. Because the tax level *t*, used in the price change calculation, is subject to later sensitivity analyses, as an intermediate step, the carbon footprint, *CF*, of household consumption of income group *q* is calculated by multiplying the carbon intensities with household expenditures for all consumption categories *K*:

$$CF_q = (e_K^{dir} + e_K^{ind}) * i_{Kq} \tag{6}$$

For this calculation the direct and indirect emissions e_K^{dir} and e_K^{ind} are converted from tCO_2/US$ to tCO_2/NGN to be compatible with household expenditure data i Kq, using the purchasing power parity conversion factor for Nigeria (World Bank 2016b). Furthermore, for this calculation household expenditure data are matched with the carbon intensity MRIO data (c.f. Section 4).

5.3. Kerosene and Petrol Subsidies: Total Payments and Distribution of Income Impacts

The total and relative income impacts as well as their distribution of the existing kerosene and petrol subsidies in Nigeria are calculated separately because the environmentally extended MRIO does not serve to calculate fuel-specific price increases because all fossil fuels are aggregated into one sector. Consequently, this study can only shed light on the direct welfare impact, i.e. the subsidy impact on households from direct purchase and consumption of kerosene and petrol.

(2011 NGN/liter)	**Spot Price**	**Official retail price**	**Subsidy payment**
Kerosene	116.46	65.00	77.53
Petrol	122.38	50.00	99.63

Tab. 2: Kerosene and petrol spot price, retail price and subsidy in Nigeria in 2011 (in 2011 NGN/liter).
Note: Subsidy payments per liter are calculated as difference between spot and retail price. (adapted from (Soile and Mu 2015))

The calculation of subsidy payments and their distribution is done in three steps: First, the liter amount of kerosene and petrol consumed by each household annually is calculated, dividing total expenditure on the fuels by their respective fixed, subsidized domestic price per liter. Second, the amount of subsidy payment per liter of fuel can be calculated as the difference between their global spot market price and the fixed domestic price (c.f. Soile and Mu (2015)).[19] To retrieve total subsidy payment per household, the subsidy payment per liter is multiplied by the liter quantity of fuel consumed by each household. To obtain the relative welfare impact, total payments per household are divided by their respective total income, approximated by total expenditure. Third, the distributional effect is estimated by averaging the total and relative (to income) household subsidy revenues over the ten income groups.

5.4. Closing Infrastructure Access Gaps: Costs and Distribution

The total cost of closing infrastructure access gaps in Nigeria until 2030 is estimated separately for water and sanitation, electricity and telecommunication, following Jakob et al. (forthcoming). Necessary investments are assumed to be carried out over a horizon of 15 years, between 2015 and 2030 which is consistent with the timeframe of the Sustainable Development Goals (Griggs et al. 2013). Estimates are expressed in per capita costs and include the provision as well as operation and maintenance (O&M). As infrastructure is expected to be constructed gradually until 2030, annual recurrent costs are taken into account only for half of the time span, i.e. 7.5 years. The calculations are based on different previous studies and estimates:

Access to drinking water and sanitation are understood in accordance with the World Bank's definition (World Bank 2016b): An "improved water source" includes piped water within the house or yard, public tabs or standpipes, tube wells, boreholes, protected springs and rain water collection. "Improved sanitation" is defined as flush toilets to piped sewage or septic tanks, ventilated improved pit latrines or composting toilets. A World Health Organization (WHO) study by Hutton (2012, Annex C/D), analyzing investment needs with respect to the Millennium Development Goals (MDGs), provides country-specific unit and recurrent costs for improved water and sanitation provision, including the planning, construction, training, protection and O&M of installed units. Per capita costs for water and sanitation access provision until 2030, W/S_{pc}, are calculated respectively:

[19] As described in detail in footnote 3, the subsidies analyzed in this study are, thus, what is referred to as pre-tax subsidies, accounting only for their fiscal, but not for their external costs (D. Coady et al. 2015).

$$W/S_{pc} = AC_{ws} * \frac{RC_{ws}}{5} * 7.5 \tag{7}$$

where access costs, AC_{ws}, are total costs to achieve universal water or sanitation access by 2030, in US$ per capita in Nigeria. Recurrent costs in percent of total costs, RC_{ws}, given for the time span 2010 until 2015 in Nigeria (Hutton 2012, Annex C/D), are annualized and spread over half the time until 2030. While Hutton (2012) provides separate estimates for rural and urban areas, for reasons of consistency, this study uses an average of both.

Cost projections for electricity access as well as for providing a minimum amount of electricity are based on the MESSAGE-Access energy system model (Pachauri et al. 2013).[20] It is a dynamic linear optimization model based on data from nationally representative household surveys. Considering access by means of grid connection or decentralized sources, the model provides estimates for different regions, taking into account their respective heterogeneous economic conditions, energy supply potentials and population densities as well as preferred energy choices of poor populations living in rural or urban areas. Data for the Sub-Saharan African region are used. The model differentiates rural and urban provision. As only the rural costs are used in this study, neglecting cost-reducing factors like economies of scale, water and sanitation cost estimates are expected to be conservative. Per capita costs are:

$$E_{pc} = ARC_e \tag{8}$$

where ARC_e is the cost of new connection, including recurrent O&M costs, in US$ per capita, in Sub-Saharan Africa.

Telecommunication access provision costs use Jakob et al.'s (forthcoming) estimates for mobile connection and usage costs. While access estimates include both landline and mobile connections, it is assumed that all new connections are mobile phones which is in line with observations from currently proliferating African countries (Aker and Mbiti 2010). Per capita mobile phone connection costs until 2030 are calculated as:

$$T_{pc} = AC_t + UC_t + AC_t * RC_t \tag{9}$$

In the absence of consistent data, a conservative fixed access cost, AC_t, is chosen based on findings of a range of different studies reported by Rothman et al. (2014). Usage costs, UC_t,

[20] With regard to the wide range of cost estimates from previous studies (Rothman et al. 2014), the MESSAGE-Access model is hoped to produce more comprehensive estimates.

assume a fixed minute cost for an air time of 10 minutes per day per capita and recurring costs, RC_t, expressed in percent of annual access costs, are again included for half of the time until 2030.

The costs for providing access to each infrastructure type within the timeframe between 2015 and 2030 are estimated in 2011 US$ per capita as shown in Tab. 3. They range from US$ 44 per capita for the provision of improved water until 2030, telecommunication access provision is much more expensive at US$ 811.

	improved water	improved sanitation	telecommunication	electricity
2030 Per Capita Cost	US$ 44	US$ 235	US$ 811	US$ 371

Tab. 3: Average per capita costs of infrastructure provision and operation and maintenance between 2015 and 2030, by infrastructure type, in 2011 US$.

In a final step, total costs and the distribution of closing infrastructure access gaps in Nigeria until 2030 are calculated for the four types of infrastructure, based on household survey data. Qualitative questions in the survey inform about the type of water source, the type of latrine, the source of electricity, if any, and phone use by household. For consistency reasons, the distribution effect is expressed in average per capita access gaps per income group. For total costs, the per capita share of population without access is determined for the survey year, using headcounts per household. These percentages are multiplied with the UN medium population forecast (UN 2015b) for Nigeria in 2030 in order to retrieve the total per capita access gaps per infrastructure type. The respective 2030 estimates are multiplied with W_{pc}, S_{pc}, E_{pc} and T_{pc} (Eq (7) to (9)) to estimate total costs in US$.

5.5. Comparison of Carbon Revenues and Infrastructure Investment Needs with Sensitivity Analysis

In order to assess to what extent revenues from carbon pricing reform would suffice to provide universal infrastructure access in Nigeria, total revenues from carbon pricing reform are compared to total investment needs for the timeframe between 2015 and 2030. The results are then compared under different assumptions in a sensitivity analysis. Importantly, only carbon tax revenues are fully included in the comparison because due to highly volatile and unforeseeable global crude oil prices, forecasting foregone subsidy payments for several years would be highly unreliable.

For consistency reasons, the calculation of total carbon tax payments is also based on the UN medium population forecast (UN 2015b) for Nigeria. Assuming that per capita carbon footprints remain unchanged, total tax revenues are calculated for three different tax rates as follows:

$$\sum_{i=2015}^{2030} Pop_i * CF_{pc} * t \tag{10}$$

where Pop_i is the total Nigerian population in year i, CF_{pc} is the constant per capita carbon footprint, in tCO_2, and t represents the three carbon tax levels, in US$ 2, 10 and 15 per t CO_2.[21] The resulting estimate of total carbon tax payments is conservative because average per capita carbon footprints are expected to grow with economic development until 2030 (c.f. Jakob, Haller, and Marschinski 2012).

The results for each of the three tax levels are then compared to the cost estimates for each infrastructure type (calculated in 5.4), expressed as percentage shares of total revenue divided by total cost. Thus, the percentage shares indicate the extent to which universal access could be achieved for each infrastructure type using total carbon revenues from each tax rate. Finally, a sensitivity analysis accounts for the uncertainties and potential inaccuracies of cost estimates described in 5.4 and 5.6 regarding the relationship between the level of investment and the actual quality and quantity of infrastructure provided. As cost estimates can, thus, be either largely over- or underestimated, besides the baseline investment need, cost scenarios of +/- 50 percent are included in the comparison.

5.6. Limitations

The results of this analysis need to be evaluated in due consideration of a number of methodological limitations and assumptions: First, the price changes estimated in 5.1 based on environmentally-extended MRIO are subject to a few inherent limitations: Most prominently, MRIO is a simple parsimonious price shifting model which assumes complete price inelasticity. Potential price-induced fuel switches or efficiency measures in the production process are not taken into account. Instead the full pass through of higher production costs to domestic consumer prices is expected. Therefore, the calculated price changes, respective tax payments as well as revenues should be interpreted as short-term estimates or upper bounds of long-

[21] Because no estimates of marginal abatement cost curves for Nigeria are available, the tax rates were chosen independent of optimality considerations, but in line with the lower globally available carbon tax rates (compare (World Bank 2016b). The tax rates applied in this study are below estimates of globally optimal carbon prices which range between US$ 20 and US$ 120 per tCO_2e (Jakob et al. (forthcoming)).

term estimates.[22] Furthermore, the estimates of tax-induced price changes implicitly assume that goods are non-traded. An upstream carbon tax, as it is suggested in this paper, can only be imposed on domestically purchased fuels and emissions throughout the domestic supply chain. Otherwise prices of imported goods would have to be raised by means of border tax adjustments according to their respective carbon content which would be politically and administratively challenging.[23] On the contrary, the non-traded assumption is not expected to largely distort results because most of the indirect price increases are due to higher costs of domestic transport for distributing goods and services, a price component which is inherently domestic (Arze del Granado, Coady, and Gillingham 2012, 2237).

Second, carbon footprints, tax payments and relative welfare impacts estimated in 5.2 by combining MRIO and household expenditure data are subject to a number of limitations: Again, the method implicitly assumes complete inelasticity, i.e. households do not reduce the impact of a tax by changing their consumption baskets and substituting away from carbon intensive goods Arze del Granado, Coady, and Gillingham (2012). Another assumption in the calculation of the distributional effects is that the purchasing power of consumers stays the same across income groups and regions, i.e. that the amount of goods acquirable for one monetary unit is independent of the standard of living. Really, however, it can be expected that very wealthy households purchase more expensive goods, so that on aggregate their carbon footprint might be overestimated (c.f. Kerkhof, Nonhebel, and Moll 2009). Furthermore, both the MRIO data as well as household consumption data are distorted by the pre-existing subsidies on kerosene and petrol. In absence of the subsidy, less or other types of fuel as well as less carbon intensive goods might be consumed by industry and households, so that observed data might overestimate the 'true' carbon intensity of consumption. Analyzing fuel consumption patterns in urban areas in Nigeria, Nwachukwu and Chike (2011) find high price elasticities of demand, indicating excessive fuel consumption due to the subsidy regime. Another shortcoming is that the model used in this study cannot measure the welfare effect of carbon prices through income. Impacts of abatement activities on wages, returns to capital and labor supply can be substantial, as found by Beck et al. (2015) in British Colombia and Fullerton

[22] The advantage of a static MRIO compared to a Computer-based General Equilibrium (CGE) model is that it is much less data and modeling intensive. Because CGE models require the specification of utility and profit functions, implicit demand functions and commodity and factor market structures, they would necessitate strong assumptions due to a lack of reliable information and data on the Nigerian economy (c.f. Beegle et al. 2016; Arze del Granado, Coady, and Gillingham 2012, 2236–7).

[23] Concerning the feasibility and effectiveness of border tax adjustments refer e.g. to Jakob, Marschinski, and Hübler (2013) and Böhringer, Rutherford, and Balistreri (2012).

(2009) in the UK. Moreover, the carbon intensities calculated with the environmentally-extended MRIO are sector averages which might result in imprecise estimates of carbon content of disaggregated consumption items. Finally, the validity of results crucially depends on the quality of underlying data which might, for example, be diminished by partially large amounts of missing data points in the household consumption survey.

Third, estimates of subsidy payments in 5.3 based on average annual spot prices might result in slight inaccuracies due to the high volatility of fossil fuel prices. Using the official subsidized retail price might also be misleading as it disregards potential illegal re-selling, fuel smuggling and other fraud which might result in higher end-consumer prices (c.f. IISD 2012). Unpredictability of volatile global crude oil prices also makes it impossible to reliably forecast total future subsidy payments over a longer time horizon. Finally, the subsidy payments accruing to the government which are extrapolated from the described calculations only account for direct fuel consumption in the household sector, and therefore only account for a fraction of total subsidies.

Fourth, the estimates of infrastructure provision costs and distribution described in 5.4 are subject to a number of assumptions and uncertainties which might limit their accuracy: First, the assumption that, without explicit intervention, the share of population lacking access to certain types of infrastructure in the year 2030 will remain the same as in the survey year disregards both urbanization[24] as well as intrinsic synergies between infrastructure and economic growth. Instead it can be expected that with economic growth gaps start to shrink - at least in terms of percent of population - as part of the economy's development process. However, reliable growth forecasts especially for Nigeria do not exist for the relevant 2030 horizon and, moreover, the level of economic performance does not suffice to explain the level of infrastructure development (Jakob et al. (forthcoming); Onyeji, Bazilian, and Nussbaumer 2012; Winkler et al. 2011). Second, infrastructure investments are likely to be undertaken to some extent by the private sector and, thus, do not have to be entirely financed by the government. Universal access would then require fewer public funds than expected in this study. This should be especially expected in the revenue generating telecommunication industry where private sector involvement is therefore common (Jakob et al. (forthcoming)). For these two

[24] Between 2010 and 2015 the average annual rate of urbanization in Nigeria was rather significant with 4.7 percent (CIA 2016). However, this information does not allow for predicting how percentage shares of infrastructure access within the population might shift as urbanization could entail positive as well as negative effects.

reasons, the overall infrastructure cost estimates used in this study should be regarded as conservative numbers. However, high rates of corruption, misappropriation as well as low efficiency of public expenditure and service delivery in Nigeria might reduce quality and quantity of infrastructure actually provided relative to investments (Barungi, Ogunleye, and Zamba 2015; Siddig et al. 2014). Additional inaccuracies arise from using regional and global estimates for estimating the cost of telecommunication and electricity provision as well as from converting from household level data to per capita access; both can result in under- or overestimation of access gaps and costs. Finally, cost estimates are sensitive to uncertain future technology innovations and costs. These considerations are taken into embraced in the sensitivity analysis in 5.5.

6. Results

The analyses carried out in this paper predominantly point toward regressivity of subsidies and progressivity of both an economy-wide carbon tax as well as infrastructure investments in Nigeria. First, carbon intensity of consumption and the distribution of the total and relative income impact of respective tax payments are presented (6.1). For better representation and more detailed insights, consumption is broken down in five direct and indirect product categories. Second, direct energy consumption patterns as well as the distribution of income gains from the kerosene and petrol subsidies are described (6.2), followed, third, by the distribution of infrastructure access by income quintiles (6.3). In a final step (6.4), the estimates of total infrastructure investment needs and tax revenues until 2030 are compared and briefly discussed in terms of their overall distributional effect on per capita basis.

6.1. Carbon Tax: Total Payments and Distribution of Income Impacts

In order to investigate the carbon intensity of household consumption and respective tax payments in further detail, direct and indirect energy consumption are further broken down into expenditures on fossil fuels and electricity (direct) as well as on public transport, other goods and services and on food (indirect).[25]

[25] For a full convergence table for the matching of GTAP sectors with the five categories refer to Appendix B.

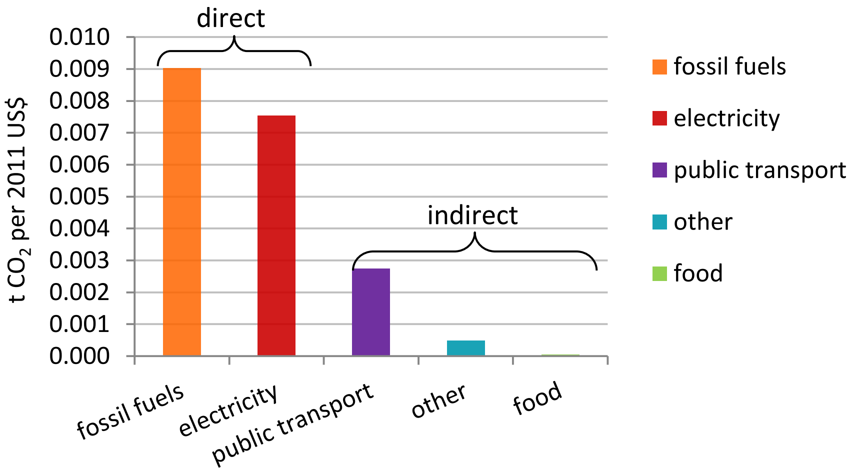

Fig. 2: Average carbon intensities by product category in Nigeria in 2011, in tons of CO_2 per PPP-adjusted 2011 US$

Fig. 2 shows the average carbon intensities of all products subsumed in each category, i.e. the tons of CO_2 embodied in one US$ of their consumption. The monetary values represent 2011 US$ which are adjusted for purchasing power parity (PPP), using the conversion factor for Nigeria (World Bank 2016b). Fossil fuel and electricity use, i.e. direct energy consumption for cooking, heating, lighting and private transport, are by far the most carbon intensive categories. This finding reassures the presumption that, as a consequence of carbon pricing, price changes of energy commodities will be largest. Among indirect consumption categories in Nigeria, public transport is most carbon-intensive, but still is less than a third as carbon-intensive as fossil fuels. Other goods and services which comprise, for example, clothing and water use are comparatively little carbon intensive and emissions from consumption of food products are even lower relative to each monetary unit.[26] Importantly, in the case of an economy-wide carbon tax, these carbon intensities can be directly interpreted as relative tax-induced price change of each product category.

[26] The carbon intensity data account only for energy-related CO_2 emissions (because those are subject to the upstream carbon tax). If non-energy-related sources of GHG emissions, such as methane or nitrous oxide emissions from land use, were to be included, agricultural and food products might exhibit higher carbon intensities.

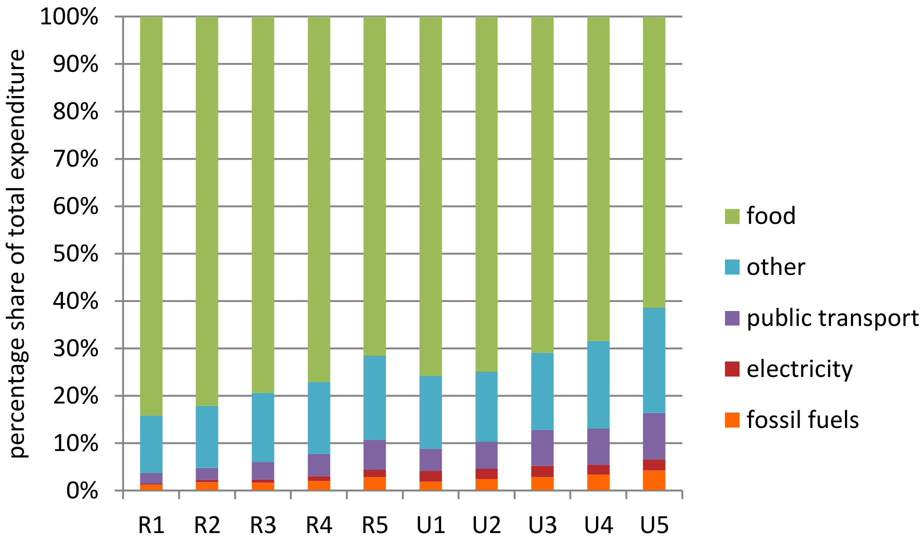

Fig. 3: Average expenditure shares by product category and income quintile in Nigeria in 2011, in percent of total average expenditure.

As expected, with rising income, smaller shares are spent on food, while the consumption of all other product categories relatively - and in total - increases with income (Fig. 3).[27] The use of public transport as well as electricity is overall higher in urban areas which indicates higher infrastructure coverage in more densely populated urban areas, but might to some extent also be due to higher average income levels. Notably, the expenditure shares of direct energy consumption are relatively small, between 1 percent (R1) and 4 percent (U5), which is likely to be attributable to the large amounts of non-purchased traditional biomass used for cooking and heating as discussed below (c.f. Fig. 5 and Excursus). Increasing shares of all (carbon-intensive) product categories except for food already indicate that an economy-wide carbon tax might be progressively distributed across income groups. This assumption is reassured by Fig. 4 which shows both the total per capita carbon footprint (bar chart) as well as the relative welfare impact of a US$ 10 tax per ton of CO_2 (lines) across income groups.

[27] For a brief description of the socio-economic characteristics of the income quintiles refer back to Section 4.

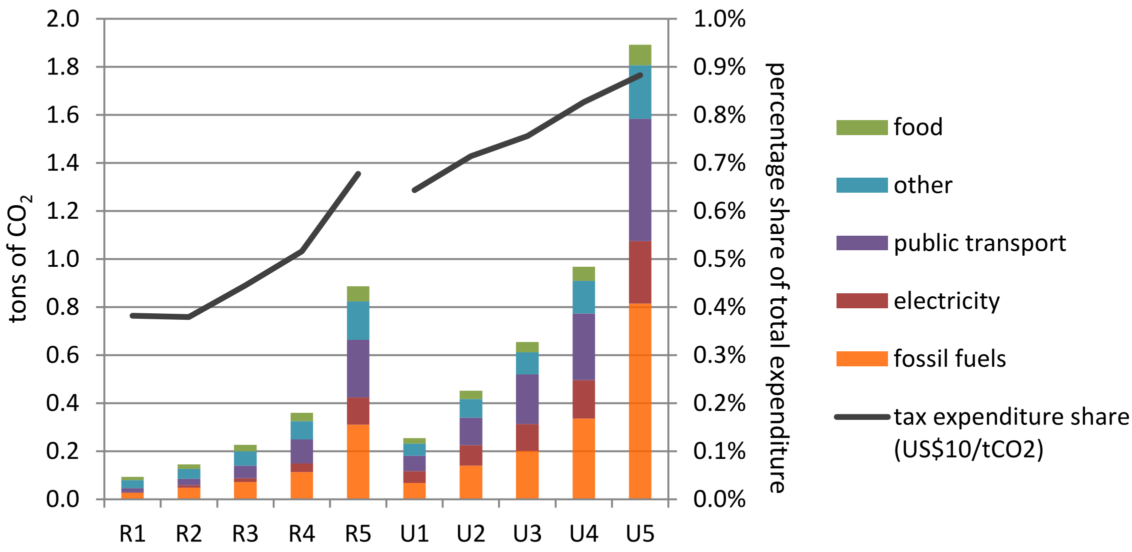

Fig. 4: Average per capita carbon footprints, in tons of CO_2 (bar chart), and income impact of US$ 10 tax per tCO_2 (PPP-adjusted), as percentage share of tax payments of annual per capita expenditure (line chart).

Clearly, the share of carbon tax payments in total annual expenditure which is used as proxy for tax-induced income loss rises as income increases, making carbon taxation progressive (line chart). For households in the bottom rural quintile R1, the income impact would be only 0.4 percent while it would reach almost 0.9 percent for the richest urban quintile. Generally, the percentage shares increase rather steadily across all income quintiles from R1 to U1. This indicates that the relative carbon intensity of consumption not only increases with income, but also that urban households tend to consume relatively more carbon-intensive goods. For example, the average per capita footprint of households in R2 is only 2/3 of that of households in U1 even though both household groups have comparable income levels. Partially, again this can be attributed to higher shares of electricity and public transport in urban consumption baskets due to wider infrastructure coverage. Especially, the share of direct emissions from fuel combustion and electricity use increases. A comparison of the share of direct versus indirect emissions in the total footprint shows that the share of indirect emissions rather steadily decreases with rising income as well as from rural to urban, which is exactly in line with findings by Siddig et al. (2014). R1 exhibits a share of 70 percent of indirect emissions, U1 a share of 54 percent and U5 a share of 43 percent of indirect emissions in the total footprint.[28] Total per capita carbon footprints range from 0.1 tCO_2 in R1 up to 1.8 tCO_2, averaging at 0.45 tCO_2 throughout the Nigerian population which is still low in global comparison. This finding

[28] This finding is roughly in line with Arze del Granado, Coady, and Gillingham (2012) who find that in African countries indirect footprints on average account for 60 percent of total carbon footprints.

is roughly in line with the World Bank estimate of 0.5 tCO_2 per capita in 2011 (World Bank 2016b).[29]

In conclusion, this analysis shows that a carbon tax would have clearly progressive income impacts in Nigeria with richer households bearing a relatively higher tax burden. This effect is found to be due to the described differences in consumption baskets of households of different income levels as well as of different geographic locations, confirming the assumption of general socio-economic differences between rural and urban residents. Furthermore, the loss of real income due to a US$ 10 tax would be relatively modest across all income groups.

6.2. Kerosene and Petrol Subsidies: Total Payments and Distribution of Income Impacts

Before a positive carbon price like a tax can be introduced, existing distortions and negative price signals, namely the kerosene and petrol subsidies in Nigeria, have to be abolished which entails a separate direct loss of income to households. In 2011, the liter price of kerosene was fixed at NGN 50 (US$ 0.34), the liter price of petrol was fixed at NGN 65 (US$ 0.44).

Before analyzing the distribution of total payments as well as relative welfare gains from the kerosene and petrol subsidy, in order to get a more comprehensive picture of energy consumption patterns, a brief look is taken at the share of different energy carriers in total direct energy consumption of household groups in Fig. 5. Direct energy expenditures are split up into kerosene, petrol, coal as well as gas and other liquid fuels, which are subsumed in the category 'fossil fuels' above, into electricity and into firewood which is excluded from the carbon tax analysis.[30] Clearly, the relative importance of petrol in households' energy mix steadily increases with income. This is also the case for kerosene with the exception of the two richest urban quintiles. While households in U4 and U5 still supply a larger part of their energy needs with liquid fuels, petrol is relatively more important for their energy use. As expected, the share of firewood declines with income as well as between rural and urban areas as total energy consumption increases. While Fig. 5 provides an overview of energy use patterns, the analysis of the distribution of subsidy payments necessitates information on the fuels' total expenditure shares.

[29] The difference between estimates can largely be attributed to the fact that the World Bank includes emissions from solid biomass such as firewood, while emissions from burning biomass are excluded from this study as they would not be subject to carbon taxation.

[30] The NBS survey results suggest that typically only between 3 and 10 percent of the firewood used is purchased so that market-based regulation of its use, e.g. through a tax, is virtually impossible.

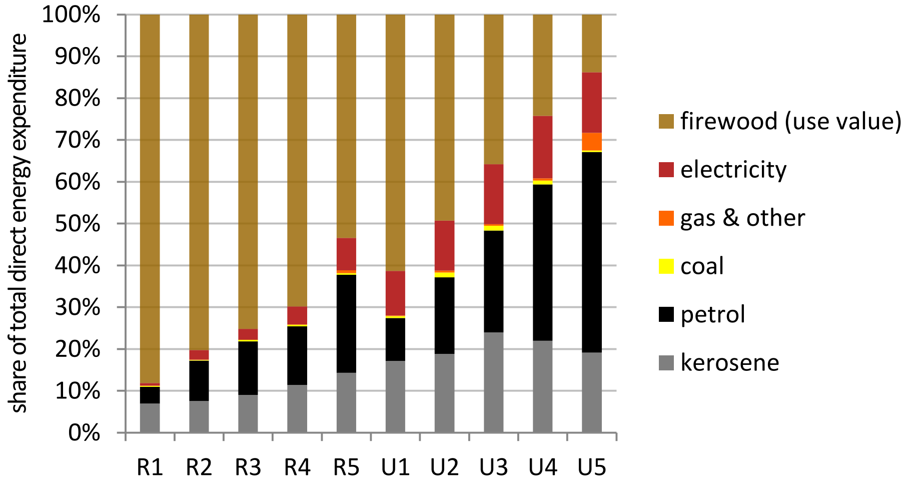

Fig. 5: Average shares of total expenditure on direct energy consumption by energy source and income quintile in Nigeria in 2011, in percent of total average energy expenditure. Note: The expenditures on firewood represent a self-estimated equivalent market value of the firewood used, including purchased and non-purchased wood. Including only actual expenditures would largely distort the results as the share of purchased firewood is very small.[31]

Fig. summarizes the results for the petrol subsidy. The bar chart depicts annual per capita subsidy revenues in 2011 US$, averaged across income groups. The line chart shows the average welfare gain from subsidy payments for households of different income groups, measured as percentage share of total annual expenditure.

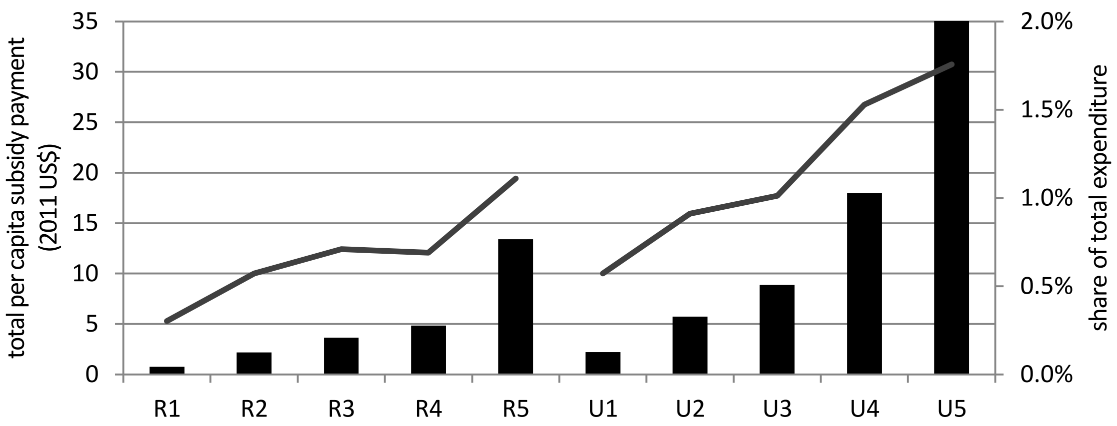

Fig. 7: Petrol subsidy: Average per capita payments, in 2011 US$ (bar chart), and income impact, as percentage share of total expenditure (line chart), by income groups in Nigeria in 2011.

The distribution of income gains from the petrol subsidy is strongly regressive, that is with higher income levels the welfare gain increases relative to total income. While at the lowest income level (R1) the income gain is only 0.3 percent, it climbs as high as 1.76 percent in the highest quintile (U5). Again, the line chart indicates that among urban households the con-

[31] The self-reported market value of freely obtained firewood has to be treated as rough estimate. Bacon, Bhattacharya, and Kojima (2010) note that due to large geographic and temporal price variation the relationship between quantity and value is weak.

sumption share of petrol is overall slightly higher than in rural areas. The steep jumps toward the last rural R5 and the second to last urban U4 could be due to increased private transport. A mean income of between US$ 2,300 (U4) and US$ 2,600 (R4) could then be interpreted as threshold to own a private vehicle. Total per capita subsidy payments are distributed accordingly with the largest amounts being paid to those with presumably the highest standard of living. On average, a person in the lowest quintile (R1) receives annually US$ 0.8, rising to US$ 13.4 in the highest rural quintile R5 and climaxing at US$ 35.3 per person in the richest urban quintile (U5) in 2011.[32]

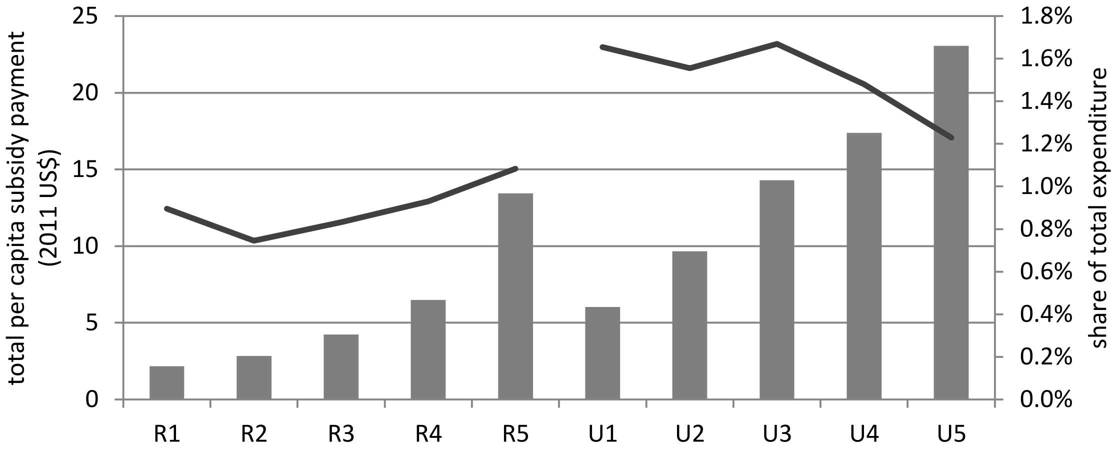

Fig. 8: Kerosene subsidy: Average per capita payments, in PPP-adjusted 2011 US$ (bar chart), and welfare impact, as percentage share of total expenditure (line chart), by income groups in Nigeria in 2011; Note: For reasons of better comparability, total per capita subsidy payments (bar chart) are *not* adjusted for purchasing power parity.

Results concerning the distribution of the kerosene subsidy are slightly less clear (c.f. 8). With the exception of the bottom quintile (R1), in rural areas subsidy payments are distributed regressively, with relative income gains rising with income, while among urban quintiles the distribution is neutral or slightly progressive.[33] At around 1.65 percent of total income, poorer urban households in U1 to U3 have the highest relative income gain, indicating that relative to income their kerosene expenditures are highest. This quasi regressive distribution is largely due to the fact that the highest two urban quintiles supply the major portion of their steeply rising energy demand with petrol, so that overall kerosene takes a smaller share while total per capita kerosene consumption is still higher than in poorer households (see Fig. 5). Again, the largest annual per capita payments of up to US$ 23 (U5) are captured by wealthier parts of society.

[32] Annual estimates of relative and total subsidy payments are highly dependent on variations of the global crude oil price. The estimates in this study are to be interpreted as averages for the year 2011 only.

[33] This result is roughly in line with Siddig et al. (2014) who find a neutral distribution of the kerosene subsidy.

	Kerosene	Petrol
R1	4.34%	1.78%
R2	5.23%	4.62%
R3	7.01%	6.96%
R4	9.35%	8.02%
R5	14.55%	16.73%
U1	7.27%	3.05%
U2	10.17%	6.94%
U3	13.30%	9.49%
U4	14.54%	17.34%
U5	14.24%	25.07%

Tab. 4: Percentage share of total kerosene and petrol subsidy payments, by income groups in Nigeria in 2011; Note: The percentages are shares of total subsidy payments received directly by households, not including subsidy gains from marketers or industry.

Finally, irrespective of the relative distribution of subsidy payments, there is substantial leakage of payments to higher income groups. Tab. 4 lists each income group's percentage shares of total subsidy payments received directly by the household sector in Nigeria in 2011. Shares steadily increase with rising income. Importantly, the share of total population declines with higher income groups (c.f. Tab. 1). Thus, for example, households in the highest urban quintile U5 represent 4.9 percent of the population, but capture 14.2 percent of total kerosene subsidy payments to households and more than a quarter of petrol subsidy payments. Similarly, the richest rural group R5 represents 8.6 percent of the population, but captures 14.6 and 16.7 percent of the kerosene and petrol subsidy received by households. Due to the larger total per capita payments, high income groups capture a disproportionally higher share of total payments. This is also true for the kerosene subsidy even though it partially exhibits progressive distribution.

In conclusion, neither the petrol nor the kerosene subsidy serve as instrument for pro-poor income redistribution. This analysis shows that income gains from the petrol subsidy are strongly regressive in Nigeria with richer households receiving higher dividends relative to total income. This is due to the fact that with rising income petrol gains in relative importance in the energy mix. The distribution of kerosene tax payments is neutral or slightly progressive. However, in terms of total payments, leakage to a small and very rich upper class is found to be substantial. Furthermore, gains in real income among the poorest income groups are found to be relatively modest for both subsidy schemes.

6.3. Closing Infrastructure Access Gaps: Costs and Distribution

The analysis of the distribution of infrastructure access gaps across household groups in Nigeria indicates that, as expected, access improves with rising income (c.f. Fig.). Overall, the diagram reveals that access shares rise throughout all quintiles R1 to U5, indicating not only that access improves with higher income, but also that at comparable income levels a larger share of urban residents has access. Especially electricity access rises steeply throughout all quintiles R1 to U5. While in the case of improved drinking water the per capita access share per income group does not fall below 50 percent even in the bottom rural quintile R1, only 13 percent in R1 have access to electricity. Notably, from R3 onward telecommunication access is highest among all types of infrastructure. This might indicate that telecommunication access is slightly overestimated due to the conversion from household access to per capita access. While for all other infrastructure types, this method is straightforward, in the case of personal mobile phones household access does not necessarily entail personal access. Overall, public investment to increase infrastructure provision can be expected to have a progressive distributional impact, entailing relatively larger gains and improvements in human well-being among poorer segments of the Nigerian society. This finding confirms the assumption that revenue recycling into infrastructure development could not only further overall economic performance, but could also serve as instrument for long-term pro-poor income redistribution.

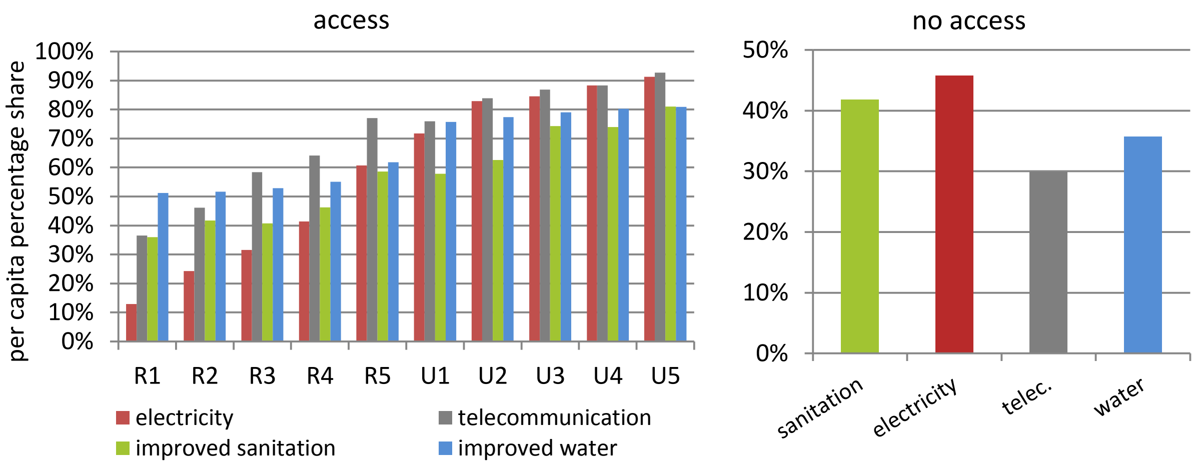

Fig. 9: Infrastructure access, as per capita percentage share of persons with access, by income group in Nigeria in 2011 (left); percentage share of total population without infrastructure access in Nigeria in 2011 (right)

With regards to the total Nigerian population, access gaps translate to 41.9 percent lacking access to improved sanitation, 45.8 percent without electricity, 29.9 percent without a mobile phone or landline and 35.7 percent with no access to an improved source of drinking water (c.f. Fig. (right)). While the estimate for drinking water is in line with the World Bank's estimate (65 percent with access), the estimate for sanitation access is more optimistic than that of the World Bank (30 percent with access) (World Bank 2016b).[34] Both telecommunication as well as electricity access estimates are also slightly more optimistic than the results of Jakob et al. (forthcoming) who find 40 percent and 52 percent respectively (for 2010).

6.4. Comparison of Carbon Revenues and Infrastructure Investment Needs with Sensitivity Analysis

Finally, total investment needs, tax revenues as well as subsidy savings are compared. For this purpose, total revenues between 2015 and 2030 are calculated for three different tax levels, namely US$ 2, 10 and 15 per tCO_2. Furthermore, extrapolated to the total Nigerian population in 2030, which will grow to 273 million (UN 2015b), the percentage shares of population without access together with per capita cost estimates yield total investment needs listed in Tab. 5 to provide universal access in Nigeria between 2015 and 2030. In total they sum up to US$ 144 billion. To analyze the sensitivity of results (as described in Section 5.5), besides the baseline investment need, cost scenarios of +/- 50 percent are considered. The percentage shares, expressed as total revenue divided by total cost in Tab. 5, indicate the extent to which universal access could be achieved using total carbon revenues, split up by infrastructure type, cost scenario and tax rate.[35]

		improved water	improved sanitation	telecommunication	electricity	total
investment needs / tax level & revenue	US$	*4.25 bn*	*26.85 bn*	*66.19 bn*	*46.32 bn*	*143.61 bn*
US$ 2/tCO_2 *US$ 3.69 bn*	- 50%	173.6%	27.5%	11.2%	15.9%	5.1%
	baseline	86.8%	13.8%	5.6%	8.0%	2.6%
	+ 50%	57.9%	9.2%	3.7%	5.3%	1.7%
US$ 10/tCO_2 *US$ 18.46 bn*	- 50%	868.2%	137.5%	55.8%	79.7%	25.7%
	baseline	434.1%	68.8%	27.9%	39.9%	12.9%
	+ 50%	289.4%	45.9%	18.6%	26.6%	8.6%
US$ 15/tCO_2 *US$ 27.69 bn*	- 50%	1302.3%	206.3%	83.7%	119.6%	38.6%
	baseline	651.2%	103.2%	41.8%	59.8%	19.3%
	+ 50%	434.1%	68.8%	27.9%	39.9%	12.9%

Tab. 5: Total baseline investment needs for universal infrastructure access in Nigeria between 2015 and 2030, in 2011 US$ (non-adjusted); Comparison of total carbon tax revenues between 2015 and 2030, for tax levels of 2011 US$ 2, 10 and 15 per tCO_2, and total investment needs, by infrastructure type; sensitivity analysis assuming +/- 50% of estimated infrastructure costs. Note: Each column assumes that all revenues are invested solely in the respective type; 'total' assumes that investments are spread evenly between all types.

[34] The reason for this divergence needs to be subject to further research. It is definitely not an issue of definition of "improved sanitation" as the LSMS questionnaire uses clearly attributable terms.

[35] Importantly, each column assumes that all revenues are invested solely in the respective type; 'total' assumes that investments are spread evenly between all types.

Even in the most optimistic scenario with the highest tax level and lowest investment needs, revenues suffice to close less than 40 percent of total infrastructure gaps until 2030. Taken separately however, water investment needs can likely be almost covered even in the US$ 2 tax scenario, for sanitation the US$ 10 tax is likely to suffice and revenues from a US$ 15 carbon tax might be enough to provide universal electricity access. Telecommunication investment needs would demand for an even higher tax level. In order to provide universal access to infrastructure at baseline investment needs until 2030 a tax level of between US$ 75 and US$ 80 per tCO_2 would be necessary in Nigeria.

Importantly, Tab. 6 indicates that even at a US$ 15 tax rate, tax payments would still result in moderate annual per capita income losses between 0.6 percent (R1) to 1.3 percent (U5). For each tax level and income group, Tab. 6 contrasts the average per capita income loss due to tax payments with the chance to gain infrastructure access if public investments are spread equitably on a per capita basis.[36] It indicates, for example, that under a US$ 15 tax scenario, an average person in R1 would pay 0.6 percent of her income as tax, but would stand a 12.7 percent chance of gaining access to infrastructure, while an average person in U5 would lose 1.3 percent of her income and stand a chance of only 2.6 percent to gain infrastructure access. As expected, percentage changes of both income and access reveal progressive distributions. The columns for a US$ 2 tax indicate that while overall income as well as infrastructure access would change less than 0.2 percent and less than 2 percent respectively (column 'access'), if revenues were invested solely in the provision of improved drinking water substantial improvements could be achieved, ranging from 42 percent chance of access gains (R1) to 17 percent (U5). The progressivity of electricity access gains under a US$ 15 tax scenario would be even more pronounced. While losing only 0.6 percent of her income, a person in the poorest rural income group R1 who does not yet have access to electricity would on average have a 52 percent chance of gaining access until 2030.

[36] Importantly, each column assumes that all revenues are invested solely in the respective type, W (improved water), S (improved sanitation), T (telecommunication) or E (electricity); 'access' assumes that all infrastructure types are supplied evenly.

	US$ 2						US$ 10						US$ 15					
	income loss (%)	W	S	T	E	access gain (%	income loss (%)	W	S	T	E	access gain (%)	income loss (%)	W	S	T	E	access gain (%)
R1	- 0.08	+ 42	+ 9	+ 4	+ 7	+ 1.7	- 0.38	+100	+ 44	+ 18	+ 35	+ 8.5	- 0.57	+ 100	+ 66	+ 27	+ 52	+ 12.7
R2	- 0.08	+ 42	+ 8	+ 3	+ 6	+ 1.5	- 0.38	+100	+ 40	+ 15	+ 30	+ 7.6	- 0.57	+ 100	+ 60	+ 23	+ 45	+ 11.4
R3	- 0.09	+ 41	+ 8	+ 2	+ 5	+ 1.4	- 0.45	+100	+ 41	+ 12	+ 27	+ 7.0	- 0.67	+ 100	+ 61	+ 17	+ 41	+ 10.4
R4	- 0.10	+ 39	+ 7	+ 2	+ 5	+ 1.2	- 0.52	+100	+ 37	+ 10	+ 23	+ 6.2	- 0.77	+ 100	+ 55	+ 15	+ 35	+ 9.3
R5	- 0.14	+ 33	+ 6	+ 1	+ 3	+ 0.9	- 0.68	+100	+ 28	+ 6	+ 16	+ 4.6	- 1.02	+ 100	+ 43	+ 10	+ 24	+ 6.8
U1	- 0.13	+ 21	+ 6	+ 1	+ 2	+ 0.8	- 0.64	+100	+ 29	+ 7	+ 11	+ 3.8	- 0.97	+ 100	+ 43	+ 10	+ 17	+ 5.7
U2	- 0.14	+ 20	+ 5	+ 1	+ 1	+ 0.6	- 0.71	+ 98	+ 26	+ 4	+ 7	+ 3.0	- 1.07	+ 100	+ 39	+ 7	+ 10	+ 4.5
U3	- 0.15	+ 18	+ 4	+ 1	+1	+ 0.5	- 0.76	+ 91	+ 18	+ 4	+ 6	+ 2.4	- 1.13	+ 100	+ 27	+ 6	+ 9	+ 3.6
U4	- 0.17	+ 17	+4	+ 1	+ 1	+ 0.4	- 0.83	+ 86	+ 18	+ 3	+ 5	+ 2.2	- 1.24	+ 100	+ 27	+ 5	+ 7	+ 3.3
U5	- 0.18	+ 17	+ 3	+ 0	+ 1	+ 0.3	-0.88	+ 83	+ 13	+ 2	+ 3	+ 1.7	- 1.32	+ 100	+ 20	+ 3	+ 5	+ 2.6

Tab. 6: Average per capita income loss and infrastructure access gains at different tax levels until 2030, assuming an equitable spread on per capita basis, by income group as percentage shares (adjusted for PPP). Note: Positive percentages of access gain refer only to those individuals who did not previously have access. Individuals who already have access have no gain; each column assumes that all revenues are invested solely in the respective type, W (improved water), S (improved sanitation), T (telecommunication) or E (electricity); 'access' assumes that all infrastructure types are supplied evenly; infrastructure cost estimates are from the baseline scenario.

Carbon revenues as well as infrastructure provision would be more pronounced if savings from the subsidy reform were taken into account in this analysis. Due to the highly volatile and unforeseeable global price of crude oil, forecasting foregone subsidy payments for several years would be highly unreliable. Furthermore, for the explained reasons, the subsidy payments captured and reported by households do not provide information on the actual fiscal costs of the regime. While this analysis calculates a total of US$ 2.4 billion captured by households through direct fuel consumption, the 2011 budget report of the Nigerian Ministry of Finance lists total domestic fuel subsidy payments with US$ 5.28 billion (or NGN 785.91 billion) in 2011 (FMF 2012). Notably according to this analysis, this 2011 amount would have sufficed to provide universal access to improved water by 2030. Between 2011 and 2014 the Nigerian government spent a total of 2011 US$ 23.3 billion on fuel subsidies. This amount would have, for example, sufficed to provide almost universal access to improved sanitation by 2030 (c.f. Tab. 5) (IEA 2015a). However, due to the 2016 subsidy reform and the steep decline in global crude oil prices, future subsidy costs and potential savings are expected to be much lower or even null. Therefore, this analysis includes savings from subsidies only in the distributional, but not in the overall quantitative analysis.

Concluding from the comparison of total revenues and costs, universal access to all four infrastructure types is not likely to be provided by a carbon tax in Nigeria. Therefore, certain infrastructure types should be prioritized before others. Alternatively, an even higher carbon tax of up to US$ 75 and US$ 80 per tCO_2 could be imposed to cover full investment needs. However, a respective tax reform seems currently politically infeasible due to the recent subsidy reform. Provision of each of the four infrastructure types would have a strongly progressive impact and, especially among lower income groups, tax-induced loss of real income is relatively smaller than potential infrastructure access gains. Overall, revenues even from lower tax levels can provide a first source of finance for closing infrastructure access gaps before further financial resources are available.

7. Discussion and Conclusion

While widespread carbon pricing is a necessary prerequisite for cost-effective and successful climate change mitigation, particularly in developing countries, the introduction of respective policy instruments is heavily contested due to the expected adverse effects on income distribution. Analyzing the case of Nigeria, this study investigates if revenue recycling into basic infrastructure development can serve to adequately compensate poor segments of society, reduce social inequality and, thereby, make unilateral carbon pricing a more attractive policy option.

In Nigeria, carbon pricing and infrastructure development are separately found to be progressive, that is, to benefit the poor relatively more - or respectively cost them less - than richer income groups. Both in terms of total payments and relative to income, positive carbon prices either by means of a fossil fuel subsidy reform or a carbon tax exhibit strongly progressive impacts on income distribution. This is because, relative to income, richer households were found to consume larger quantities of direct fuels, including kerosene and petrol, as well as of carbon-intensive goods and services. This evidence from Nigeria is in line with the majority of studies on developing countries reviewed in Section 2.3. Regarding total impacts, reductions in real income due to carbon taxation as well as subsidy removal were found to be relatively modest, especially among poorer income groups. Further research, adding to Siddig et al. (2014), could re-evaluate the magnitude of the distributional impact by analyzing second-order effects in Nigeria: First, an analysis of price elasticities of demand could shed light on adaptive behavior of consumers as well as producers in Nigeria. A potential finding could be that with time overall carbon intensities decrease and the tax burden shrinks. Because richer households are commonly thought of as more price elastic, the progressivity of a carbon tax could become less pronounced over time. This would indicate that carbon pricing successfully incentivizes mitigation, predominantly tackling the emissions of upper classes. Second, impacts through changes in income levels could be added to the analysis, investigating how tax-induced changes in factor prices influence households' incomes over time. Moreover, the validity of the assumption of constant purchasing power parity across income groups could be re-evaluated as it might lead to an overestimation of the consumption-based emissions of richer households and also result in overly progressive effects. Because such analyses themselves require strong assumptions due to the lack of reliable information on some parameters of the Nigerian economy, this study is based on a static analysis and estimates are to be interpreted as short-term impacts.[37] In line with previous studies on developing countries, carbon taxation is found to have positive redistributive effects, while fossil fuel subsidies fail as, least of all efficient, policy instrument for protecting poor households in Nigeria.

Investing carbon revenues to close infrastructure access gaps could indeed compensate poorer segments of society for reductions in real income due to carbon pricing, according to this analysis. All four types of basic infrastructure, namely improved water, improved sanitation, electricity and telecommunication, were found to be relatively less accessible for poor income groups in Nigeria so that, if access was increased equitably, they would benefit most: For example, under a US$ 15 tax scenario a person in a poorer rural household would on average pay around 0.6 percent of their income as tax, but would stand a chance of up to 13 percent to gain infrastructure assess, while an average person from a richer urban household would sacrifice 1.3 percent of their income, but stand a chance of only 3 percent to acquire infrastructure access. This insight adds to the general literature on infrastructure and inequality as indicated by Calderón and Servén (2014). However, concluding from the comparison of total revenues and costs, universal access to all four infrastructure types is not likely to be provided by a carbon tax in Nigeria. Universal access until 2030 would necessitate a carbon tax rate of between US$ 75 and US$ 80 per tCO_2. This seems currently politically infeasible as energy prices were just recently raised during the subsidy reform. Thus, the extent of pro-poor compensation depends on if investments are to be spread equitably or even focused on poorer rural areas. Further research could aim to improve estimates of infrastructure provision costs, investigating in further detail the reciprocal link between infrastructure and economic growth as well as the potential of private sector involvement in infrastructure investment in Nigeria. A possible outcome could be that over longer time horizons public costs might decrease more

[37] For a discussion of data availability and respective limitations for research in African countries refer to Beegle et al. (2016).

than assumed in this cost comparison. In any case, revenues even from lower tax levels could provide a first source of finance for closing infrastructure access gaps before alternative financial resources, for example from international funds, are available.

Importantly, the largest disparities in terms of infrastructure access and income occur spatially between rural and urban areas in Nigeria. Thus, universal or at least equitable infrastructure development could not only reduce inequalities between income groups, but could also mitigate existing structural differences between regions and facilitate inclusive growth. On the downside, 'redistribution' by means of infrastructure development can be problematic because access gains do not directly translate into monetary gains and, therefore, might not suffice to mitigate the tax-induced income loss of households. Furthermore, such indirect benefits from infrastructure access are likely to occur with considerable time lag between tax collection and actual construction and utilization. A possible approach to these drawbacks, which would also be in line with strategic plans by the Nigerian government, could be to focus first on universal electricity access because its current distribution is most regressive and households' monetary savings from foregone use of other energy sources might be most tangible.

In order to yield socially coherent and environmentally effective outcomes, the analyzed policy measures necessarily need to be embedded in a larger sustainability framework, deliberately redistributing in favor of the poor and promoting environmentally-friendly practices. Especially, in the power sector the tax-induced price signal might not be strong enough to incentivize efficient and clean energy supply and avoid carbon-intensive lock-ins. Furthermore, reducing the excessive consumption of unsustainable firewood in the household sector in Nigeria is indispensable for sustainable development, but cannot be achieved by means of carbon taxation. Instead it necessitates the provision of accessible and affordable alternative energy sources. In recent years, the Nigerian government has put forward concrete policy measures, such as feed-in tariffs and quota, as well as long-term goals for expansion of renewable energy sources and electrification rates. Building for instance on Oyedepo's (2014) and Aliyu et al.'s (2013) analyses of the Nigerian energy system, a detailed policy analysis could assess how the current regulatory framework would have to be adapted in order for carbon pricing and infrastructure expansion to be conductive for socially and environmentally sustainable development while also meeting Nigeria's growing energy demand.

Finally, the implementation of the analyzed policy mix in Nigeria could be hampered according to the common concern that carbon pricing is politically infeasible in developing countries. However, the Nigerian government has explicitly considered fiscal reform as instrument for climate change mitigation and acknowledged the positive economic effects of investing respective revenues in infrastructure development. It has also taken according actions, emphasizing their co-benefits: The stated reasons for partially abolishing the fossil fuel subsidy scheme were mainly its failure to redistribute pro-poor and its high fiscal costs which were crowding out other public investments, particularly in infrastructure. The expansion of infrastructure is motivated by the expected positive impact on business climate and private sector development in Nigeria. Against this background, a thorough analysis of the Nigerian political economy, including political motivations, competing interests and power constellations which influence energy and environmental policy-making, could evaluate the prospect of carbon taxation in Nigeria. Also, it could assess which factors, including the considerably lower oil prices, led to higher public acceptance during the latest subsidy reform in 2016, in contrast to the 2012 attempt. Irrespective of their political feasibility, however, the success of respective measures might be hampered by inadequate implementation due to Nigeria's poor institutional and governance capacities. High corruption and misappropriation rates as well as low efficiency of public expenditures might reduce the quality and quantity of infrastructure provision at certain investment levels (IMF 2013b). While such losses due to inefficiencies and corruption would be expected to decrease with the removal of the subsidy regime, they might increase in relation to the introduction of carbon taxation and infrastructure construction. Political fraud also negatively affects political credibility and public acceptance of reforms.

In conclusion, the systematic analysis of micro-level household data conducted in this paper finds strong evidence of the positive impact of carbon pricing as well as of infrastructure development on the reduction of social inequality in Nigeria. Loss of real income due to carbon pricing is particularly modest for lower-income households. This finding debilitates the concern that carbon pricing will disproportionally burden the poor and shows that revenue recycling into infrastructure investments could serve for further pro-poor redistribution as well as for the compensation of carbon-pricing induced income loss. Due to these positive social impacts, paired with further fiscal and economic co-benefits, the analyzed policy mix could provide an attractive option for unilateral climate change mitigation in Nigeria. Its potential to positively contribute to overall sustainable development, however, depends on the surrounding regulatory framework as well as on the institutional capacities and quality of governance of Nigerian government bodies.

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Appendix

A. Literature on Direct and Indirect Distributional Impacts of Carbon Pricing

Paper	Object of Research	Methodology	Main Results	
Wier et al. (2005)	CO_2 tax *Denmark*	Environmentally-extended IO[1] combined with hh data[2]	Regressivity; direct impact more regressive than in direct	Developed countries
Kerkhof et al. (2008)	CO_2 -only vs. GHG tax *Netherlands*	Environmentally-extended IO[1] combined with hh data[2]	Regressivity of both taxes; more pronounced for CO_2-only tax	
Feng et al. (2010)	CO_2 vs. GHG tax *United Kingdom*	Environmentally-extended IO[1] combined with hh data[2]	Regressivity of both taxes; more pronounced for CO_2-only tax	
Graigner and Kolstad (2010)	CO_2 tax *United States*	Environmentally-extended IO[1] combined with hh data[2]	Regressivity	
Rausch et al. (2010)	Carbon pricing through cap-and-trade *United States*	CGE[3]	Slight progressivity; as low income hhs receive higher share of transfers which are indexed to inflation	
Rausch, Metclaf, and Reilly (2011)	Carbon pricing *United States*	static GCE[3]	Overall neutral distribution; progressivity through changes of income offsets regressivity through changes of commodity prices	
Dissou and Siddiqui (2014)	Carbon tax *Canada*	CGE[3]	Overall progressivity; progressivity through changes of income outweighs regressivity through changes of commodity prices;	
Beck et al. (2014)	Carbon tax *British Colombia*, CA	CGE[3]	Strong progressivity; mostly driven through changes in household's income	
Shah and Larsen (1992)	Carbon tax *Pakistan*	Partial Equilibrium Model	Progressivity	Developing countries
van Heerden et al. (2005)	Carbon tax combined with food tax reductions *South Africa*	static CGE[3]	Progressivity of policy mix	
Devarajan et al. (2011)	Energy taxes vs. carbon tax *South Africa*	CGE[3]	Regressivity of both tax types; more pronounced for carbon tax, driven by water and electricity consumption	

Paper	Object of Research	Methodology	Main Results	
Brenner, Riddle, and Boyce (2007)	Carbon pricing *China*	Environmentally-extended IO[1] combined with hh data[2]	Progressivity; driven by differences income and emissions between rural and urban households	Developing countries
Datta (2010)	Fuel taxes *India*	Partial Equilibrium Model	Progressivity or neutrality of all taxes except on kerosene	
Yusuf (2008); Yusuf and Resosudarmo (2012)	Carbon tax and transport fuel tax *Indonesia*	static CGE[3]	Progressivity of both tax types; strong progressivity in rural areas, neutrality or slight progressivity in urban areas	
Arze del Granado, Coady, and Gillingham (2012)	Meta-analysis of 20 studies on fossil fuel subsidies; mainly Coady et al. (2006) and Bacon, Bhattacharya & Kojima (2010) *Cameroon, Gabon, Central African Republic, Senegal, Ghana, Mali, Congo, Burkina, Madagascar, Bolivia, Peru, Honduras, Bangladesh, Sri Lanka, Cambodia, India, Indonesia, Jordan, Lebanon*	Meta-analysis; mostly: Environmentally- extended IO[1] combined with hh data[2]	Overall neutral distribution across countries; highlighting that overall progressive direct impact might blur differences between specific fuels	

[1] Environmentally-extended Input-Output Model
[2] Household expenditure data from national survey
[3] Computer-based General Equilibrium model

B. Matching Table of Household Consumption Items with MRIO Sectors

Household Consumption Items (Variable *item_cd*; (NBS 2011)	MRIO Sectors* (GTAP 9.0; 2011)		Five Consumption Categories	
301 Kerosene 303 Gas (for lighting/cooking) 304 Other liquid cooking fuel 308 Charcoal 309 Petrol 310 Diesel	p_c	Petroleum, coal products	**fossil fuels**	**direct**
303 Gas (for lighting/cooking)	gdt	Gas manufacture		
305 Electricity including electricity vouchers	ely	Electricity	**electricity**	
13 Rice-local 14 Rice-Imported	pdr	Paddy rice	**food**	**indirect**
10 Guinea Corn/Sorghum 11 Millet 12 Maize	gro	Cereal grains nec		
43 Groundnuts 44 Other nuts/seeds/pulses 60 Bananas 61 Orange/tangerine 62 Mangoes 63 Avocado pear 64 Pineapples 65 Canned 66 Other fruits 70 Tomatoes 72 Onions 73 Garden eggs/egg plant 74 Okra-fresh 76 Pepper 77 Vegetable leaves (Cocoyam, Spinach, etc) 78 Other vegetables (fresh or canned)	v_f	Vegetables, fruit, nuts		
110 Fresh milk 111 Milk powder 112 Baby milk powder 113 Milk tinned (unsweetend) 114 Other milk products	mil	Dairy products		
40 Soya beans 41 Brown beans 42 White beans	osd	Oil seeds		
30 Cassava-Roots 31 Yam-roots 32 Gari-White 33 Gari -Yellow 34 Cocoyam 35 Plantains 36 Sweet Potatoes 37 Potatoes 38 Other roots and tuber 140 Condiments,(salt, spices,pepper,	ocr	Crops nec		
80 Chicken 81 Duck 82 Other domestic poultry 83 Agricultural eggs 84 Local eggs 85 Other eggs (not chicken) 132 Honey	oap	Animal products nec		

Household Consumption Items (Variable *item_cd*; (NBS 2011)	**MRIO Sectors*** (GTAP 9.0; 2011)		**Five Consumption Categories**	
90 Beef 91 Mutton 93 Goat 94 Wild game meat 95 Canned beef/corned beef 96 Other meat (excl. poultry)	cmt	Bovine meat products		**indirect**
92 Pork	omt	Meat products nec		
50 Palm oil 51 Butter/Margarine 52 Groundnut oil 53 Other oils and fats 302 Palm kernel oil	vol	Vegetable oils and fats		
130 Sugar	sgr	Sugar		
15 Bread 16 Maize 17 Yam flour 18 Cassava flour 19 Wheat 20 Other grains and flour 71 Tomatoes puree(canned) 75 Okra-dried 100 Fish-Fresh 101 Fish- 102 Fish-Smoked 103 Fish-Dried 104 Snails 105 Seafood (lobster, crab, prawns) 106 Canned fish/seafood 107 Other fish or seafood 131 Jams 133 Other sweets Confectionary	ofd	Food products nec		
120 Coffee 121 Chocolate drinks (122 Tea 150 Bottled water 151 Sachet water 152 Malt 153 Soft drinks (Coca cola, spirit etc) 154 Fruit juice canned 155 Other Non-acoholic drinks 160 Beer (local and imported) 161 Palm wine 162 Pito 163 Gin 164 Other alcoholic beverages 1101 Cigarettes or tobacco	b_t	Beverages and tobacco products		
411 Ankara, george materials 412 Other clothing materials 501 Carpets, rugs, drapes, curtains 502 Linen - towels, sheets, blankets 503 Mat - sleeping or for drying maize flour 504 Mosquito net 505 Mattress	tex	Textiles	**other**	
401 Infant clothing 402 Baby nappies/diapers 403 Boys tailored clothes 404 Boys dress (ready made) 405 Girls tailored clothes	wap	Wearing apparel		

Household Consumption Items (Variable *item_cd*; (NBS 2011)	**MRIO Sectors*** (GTAP 9.0; 2011)		**Five Consumption Categories**	
406 Girls dress (ready made) 407 Men tailored clothes 408 Men dress (ready made) 409 Women tailored clothes 410 Women dress (ready made)				**indirect**
413 Boy's 414 Men's shoes 415 Girl's 416 Lady shoes	lea	Leather products		
307 Firewood	lum	Wood products		
314 Toilet 426 Books (not for school)	ppp	Paper products, publishing		
313 Soap and washing powder 315 Personal care goods (razor blades, cosmet- 316 Vitamin supplement 317 Insecticides, disinfectant an cleaners	crp	Chemical, rubber, plastic products		
311 Light bulbs/globes 419 Bowls, glassware, plates, silverware etc 420 Cooking utensils (cookpots, stirring spoons 421 Cleaning utensils (broom, brushes etc) 422 Torch/flashlight 423 Umbrella and raincoat 425 Stationery items (not for school)	ome	Machinery and equipment nec		
312 Water	wtr	Water		
323 Motor vehicle service repair or parts 324 Bicycle service repair or parts 428 Night's lodging in rest house or hotel 327 Repairs & maintenance to dwelling	trd	Trade		
318 Postal (incl. stamps, courier) 319 Recharge cards 320 Landline charges 321 Internet services	cmn	Communication		
322 Recreational (cinemas, video/dvd rental) 325 Wages paid to staff/maid/lawnsboy	ros	Recreational & services		
1104 Public transport (bus, rail, boat, etc)	otp	Transport nec	**public transport**	

* For full a description of GTAP Sectors refer to Appendix C below.

C. GTAP Detailed Sectoral List

Number	Code	Description*
1	pdr	Paddy Rice: rice, husked and unhusked
2	wht	Wheat: wheat and meslin
3	gro	Other Grains: maize (corn), barley, rye, oats, other cereals
4	v_f	Veg & Fruit: vegetables, fruitvegetables, fruit and nuts, potatoes, cassava, truffles,
5	osd	Oil Seeds: oil seeds and oleaginous fruit; soy beans, copra
6	c_b	Cane & Beet: sugar cane and sugar beet
7	pfb	Plant Fibres: cotton, flax, hemp, sisal and other raw vegetable materials used in textiles
8	ocr	Other Crops: live plants; cut flowers and flower buds; flower seeds and fruit seeds; vegetable seeds, beverage and spice crops, unmanufactured tobacco, cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets, plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes, sugar beet seed and seeds of forage plants, other raw vegetable materials
9	ctl	Cattle: cattle, sheep, goats, horses, asses, mules, and hinnies; and semen thereof
10	oap	Other Animal Products: swine, poultry and other live animals; eggs, in shell (fresh or cooked), natural honey, snails (fresh or preserved) except sea snails; frogs' legs, edible products of animal origin n.e.c., hides, skins and furskins, raw , insect waxes and spermaceti, whether or not refined or coloured
11	rmk	Raw milk
12	wol	Wool: wool, silk, and other raw animal materials used in textile
13	frs	Forestry: forestry, logging and related service activities
14	fsh	Fishing: hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing
15	coa	Coal: mining and agglomeration of hard coal, lignite and peat
16	oil	Oil: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
17	gas	Gas: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
18	omn	Other Mining: mining of metal ores, uranium, gems. other mining and quarrying
19	cmt	Cattle Meat: fresh or chilled meat and edible offal of cattle, sheep, goats, horses, asses, mules, and hinnies. raw fats or grease from any animal or bird.
20	omt	Other Meat: pig meat and offal. preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal; greaves
21	vol	Vegetable Oils: crude and refined oils of soya-bean, maize (corn),olive, sesame, groundnut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and canola, mustard, coconut palm, palm kernel, castor, tung jojoba, babassu and linseed, perhaps partly or wholly hydrogenated,inter-esterified, re-esterified or elaidinised. Also margarine and similar preparations, animal or vegetable waxes, fats and oils and their fractions, cotton linters, oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; degras and other residues resulting from the treatment of fatty substances or animal or vegetable waxes.
22	mil	Milk: dairy products
23	pcr	Processed Rice: rice, semi- or wholly milled
24	sgr	Sugar
25	ofd	Other Food: prepared and preserved fish or vegetables, fruit juices and vegetable juices, prepared and preserved fruit and nuts, all cereal flours, groats, meal and pellets of wheat, cereal groats, meal and pellets n.e.c., other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers' wares, starches and starch products; sugars and sugar syrups n.e.c., preparations used in animal feeding, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles,

Number	Code	Description*
		couscous and similar farinaceous products, food products n.e.c.
26	b_t	Beverages and Tobacco products
27	tex	Textiles: textiles and man-made fibres
28	wap	Wearing Apparel: Clothing, dressing and dyeing of fur
29	lea	Leather: tanning and dressing of leather; luggage, handbags, saddlery, harness and foot-wear
30	lum	Lumber: wood and products of wood and cork, except furniture; articles of straw and plaiting materials
31	ppp	Paper & Paper Products: includes publishing, printing and reproduction of recorded me-dia
32	p_c	Petroleum & Coke: coke oven products, refined petroleum products, processing of nucle-ar fuel
33	crp	Chemical Rubber Products: basic chemicals, other chemical products, rubber and plastics products
34	nmm	Non-Metallic Minerals: cement, plaster, lime, gravel, concrete
35	i_s	Iron & Steel: basic production and casting
36	nfm	Non-Ferrous Metals: production and casting of copper, aluminium, zinc, lead, gold, and silver
37	fmp	Fabricated Metal Products: Sheet metal products, but not machinery and equipment
38	mvh	Motor Motor vehicles and parts: cars, lorries, trailers and semi-trailers
39	otn	Other Transport Equipment: Manufacture of other transport equipment
40	ele	Electronic Equipment: office, accounting and computing machinery, radio, television and communication equipment and apparatus
41	ome	Other Machinery & Equipment: electrical machinery and apparatus n.e.c., medical, preci-sion and optical instruments, watches and clocks
42	omf	Other Manufacturing: includes recycling
43	ely	Electricity: production, collection and distribution
44	gdt	Gas Distribution: distribution of gaseous fuels through mains; steam and hot water supply
45	wtr	Water: collection, purification and distribution
46	cns	Construction: building houses factories offices and roads
47	trd	Trade: all retail sales; wholesale trade and commission trade; hotels and restaurants; re-pairs of motor vehicles and personal and household goods; retail sale of automotive fuel
48	otp	Other Transport: road, rail ; pipelines, auxiliary transport activities; travel agencies
49	wtp	Water transport
50	atp	Air transport
51	cmn	Communications: post and telecommunications
52	ofi	Other Financial Intermediation: includes auxiliary activities but not insurance and pen-sion funding (see next)
53	isr	Insurance: includes pension funding, except compulsory social security
54	obs	Other Business Services: real estate, renting and business activities
55	ros	Recreation & Other Services: recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)
56	osg	Other Services (Government): public administration and defense; compulsory social secu-rity, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., extra-territorial organizations and bodies
57	dwe	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)

* Grey sectors were not matched and are not included in Appendix B.

Source: GTAP: https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp

D. Digital Appendix: Data and Calculations

Name of File/Folder	Description
Household Survey Data	Folder contains the original 2010/2011 survey data for post planting and post harvest as provided by NBS (2011), in STATA data file format.
GTAP_CO2_gesamt5000.dta	STATA data file contains a matrix of CO_2 emission intensities (tCO_2/NGN) for all 57 GTAP sectors in Nigeria, based on GTAP 9.0 (Narayanan, Aguiar, and McDougall 2015), and all 5,000 household observations, identified by a household ID.
Stata_Code_Dorband.do	STATA do-file contains the entire code for the data preparation and analysis, referring to the original NBS data as well as the data file based on GTAP.
Stata_Output_Dorband.pdf	File contains the STATA output, i.e. the code together with the results from running the code in STATA.
Calculations_Graphs_Dorband.excel	File contains final calculations based on STATA output and graphs for visual presentation in the paper, mostly by quintile averages: - Descriptive Statistics: Income Quintiles - Expenditure Shares of Consumption Categories - Carbon Footprints, by Consumption Categories - Infrastructure Provision Costs until 2030 - Carbon Tax Payments until 2030 - Infrastructure Access Shares - Revenue-Cost Comparison - Carbon Intensities of Consumption Categories - Subsidy Payments and Distribution - Direct Energy Consumption by Source (Shares) - Purchasing Power Parity (PPP) Conversion

Statutory Declaration

by

Ira Irina Dorband

I hereby assert that my Master‘s thesis was independently composed/authored by myself, using the referred sources and support.

I additionally assert that this thesis has not been part of another examination process.

I agree~~/disagree~~ that a copy of my master thesis can be borrowed from the library.

Berlin, 14. April 2016

(Signature)