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Fighting the 'Forgotten' Disease: LiST-Based Analysis of Pneumonia Prevention Interventions to Reduce Under-Five Mortality in High-Burden Countries

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Abstract:

Despite being the primary killer of children under-five globally, pneumonia is frequently left out of international global health discourse and programme prioritisation. Renewed focus on the disease is paramount in order to reduce these preventable child deaths. Consequently, this dissertation used a qualitative methodology of secondary literature review and data analysis to explore the relationship between select pneumonia prevention interventions and under-five mortality in five high-burden pneumonia countries: Nigeria, Democratic Republic of Congo (DRC), Ethiopia, India, and Pakistan. Findings showed that clean cooking fuels, Hib3 vaccination, and age-appropriate breastfeeding practices are the three most impactful preventative interventions on under-five mortality in the five countries analysed.

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List of Abbreviations

AIM	AIDS Impact Model
DemProj	Demography Projection
DHS	Demographic Health Survey
DRC	Democratic Republic of Congo, the
GAPPD	Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea
GAVI	Global Alliance for Vaccination and Immunization
HAP	Household Air Pollution
Hib	Haemophilus Influenzae Type B
LiST	Lives Saved Tool
LMICs	Low- and Middle-Income Countries
LRI	Lower Respiratory Tract Infection
MICS	Multiple Indicator Cluster Survey
NICE	National Institute for Health and Clinical Excellence
PCV	Pneumococcal Conjugate Vaccine
PM	Particulate Matter
RCTs	Randomised-Control Trials

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1. Introduction

Pneumonia kills more children under-five, almost exclusively in low-and-middle-income countries (LMICs), than any other infectious disease. Over 870,000 children die each year – more than both malaria and diarrhoea combined (UNICEF 2019b). This severe acute lower respiratory tract infection (LRI) accounts for approximately 15% of all child deaths annually (WHO 2019c). Despite the high global burden of disease and widespread knowledge of effective prevention and treatment options, pneumonia receives little funding compared to other diseases, and is rarely prioritised on the health policy strategies of high-burden countries (Watkins et al. 2017). There is no question that the literature from international organizations and academics on pneumonia as the "forgotten killer" (Wardlaw, Johansson White, and Hodge 2006, p.1) is robust – but this has not yet translated into cross-disciplinary solidarity against the issue (The Lancet Global Health, 2018).

In 2009, WHO and UNICEF launched the integrated Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea (GAPPD), which proposes a multi-stakeholder approach to reduce the incidence of severe pneumonia and diarrhoea in children globally by 2025. The 2013 report outlines an integrated protect, prevent, and treat model, including key interventions, to address the two conditions in conjunction (WHO and UNICEF 2013). The GAPPD targets related to pneumonia are as follows:

1. Reduce under-five pneumonia morality to less than 3 per 1,000 live births
2. 75% reduction in severe under-five pneumonia incidence compared to 2010 levels

The GAPPD represents tangible goals for the reduction of pneumonia morbidity and mortality. However, the world is a long way from realizing these targets within the timeframe proposed.

Consequently, this exploratory analysis seeks to investigate the relationship between pneumonia prevention interventions and under-five mortality in five countries: Nigeria, DRC, Ethiopia, India, and Pakistan. LMICs are home to 62% of the world's under-five population, yet account for over 90% of the global burden of pneumonia and diarrhoea deaths (UNICEF 2016). Nearly 90% of these deaths are concentrated in Sub-Saharan Africa and South Asia;

the five countries selected alone accounting for the greatest number of pneumonia deaths globally (UNICEF 2012).

While evidence of the impact of pneumonia preventative interventions on under-five mortality exists, and forms the evidence-base for this analysis, few studies pull together each of these strategies and model their impact across multiple country scenarios. The justification for why childhood pneumonia should be prioritized in conjunction with these impact projections makes this dissertation unique.

Given this, the research question of this analysis is:

> *Which context-specific preventative pneumonia interventions lead to the greatest reduction in under-five mortality in selected high-burden countries?*

This dissertation is outlined as follows: section two reviews the literature on pneumonia's pathophysiology, a brief exploration of its neglect on the global health agenda, and the disease burden in the five countries selected; section three outlines the conceptual framework that serves as a foundation for this analysis; section four details the methodology employed, including the selected preventative intervention specifics and study limitations; section five presents the results and, section six concludes with examining the findings.

2. Literature Review

2.1. What is Pneumonia

Pneumonia is not a monocausal disease, there are multiple bacterial, viral, and fungal pathogens that can trigger an immune response. The most common causes of pneumonia are the bacteria *Streptococcus pneumoniae* (pneumococcal) and Haemophilus influenzae type b (Hib). Ninety distinct serotypes of pneumococcal exist and vary based on location, presenting as a number of different diseases including pneumonia, sinusitis, and meningitis (Fitzwater et al. 2012; Lucero et al. 2009). Pneumococcal alone is estimated to be responsible for 13.8 million cases of community-acquired pneumonia per year, killing approximately 500,000 children (Fitzwater et al. 2012). Hib is responsible for approximately 20% of acute LRI deaths of the unimmunized (Oliwa and Marais 2017).

The pathogens causing pneumonia are often found living in the respiratory tract and, in a majority of cases, do not result in a LRI. For most healthy adults, the immune system can counteract the pneumonia-causing pathogens rendering the host immune. However, for children under-five, older adults, and those otherwise immunocompromised, there is an increased susceptibility to infection. Without a strong defence preventing the spread through the respiratory tract, the pneumonia-causing pathogens make their way to the lungs (UNICEF 2016). The macrophages are the first line of defence and trigger the release of cytokines, a group of proteins that act as regulatory chemical messengers in the immune system. These cytokines lead to inflammation, causing the air sacs in the lungs called alveoli, where the exchange of oxygen and carbon dioxide takes place, to fill with fluid from the bloodstream (Seeker 2019). White blood cells fill the alveoli in order to counteract the infection but, in doing so, hinder gas exchange. Common symptoms of this response are difficulty breathing, coughing, fatigue, fever, nausea, or diarrhoea (Mayo Clinic 2020). Pneumonia can be acquired through droplets from coughing or sneezing but can also be spread through blood and unsafe sanitation (WHO 2019c).

2.2. Pneumonia's Neglect

In 2017, pneumonia claimed the lives of more than 800,000 children (Dadonaite and Roser 2019). Although the estimated number of annual child deaths from the disease between 2000 and 2015 has decreased by 47%, pneumonia still remains a substantial burden to public health (Brown and Head 2015). While almost all pneumonia deaths could be prevented by proper prevention, diagnosis, and treatment, deaths are decreasing far more slowly than other major killers. Despite these worrying statistics, pneumonia is rarely prioritised on the global health agenda. Recent reports from Save the Children and UNICEF, as well as the creation of the private-public Every Breath Counts coalition group, are encouraging developments to end preventable pneumonia deaths. However, national political leadership is often noticeably absent from these discussions (Watkins and Sridhar 2019).

In 2007, WHO raised concerns that international funding for health activities were being unevenly allocated across different diseases, with the majority of money going towards HIV, TB, and malaria (Greenwood, Weber, and Mulholland 2007). However, in 2015, pneumonia received just US$184 in funding per death compared to US$2120 for HIV and US$3585 for influenza (Brown and Head 2015). This lack of funding towards research and

development, dissemination of prevention and treatment options, and strengthening of primary healthcare systems are reasons why under-five pneumonia deaths have not seen a dramatic decline (Fisher Walker et al. 2013). On a national level, research has shown that high-burden countries are frequently unaware of the severity of the issue, measures that can be taken to reduce pneumonia incidence, or the overall effects that interventions may have on under-five mortality rates (Oliwa and Marais 2017).

So why, despite its high burden of disease, has childhood pneumonia been relegated on the priority list of international health partners and state governments? This analysis has identified three key factors: victim profile, perceptions of threat, and disease aetiology. While a full analysis of pneumonia's neglect is beyond the scope of this dissertation, a short exploration of why pneumonia is neglected ground the findings of this study.

Victim Profile

While pneumonia can be fatal across the life-cycle, the principal victims are children and the elderly. 75% of pneumonia deaths are concentrated within these two vulnerable populations - 809,000 deaths among children and 1.1 million deaths among the elderly over 70 (Greenslade 2018). In LMICs, the number of pneumonia deaths falls disproportionally on children while in high-income countries the elderly bear the greatest burden; two groups that frequently lack political prioritisation. Additionally, the children at greatest risk often come from the most disadvantaged positions in society – they are more likely to be malnourished and least likely to be vaccinated, correctly diagnosed or treated when symptoms of pneumonia arise.

The age of those most affected is not the only relevant consideration - pneumonia is also primarily a disease of poverty (Watkins and Sridhar 2019; Save the Children and UNICEF 2020). More affluent populations with the strongest political sway in influencing health priorities are protected from pneumonia risks and consequently, the disease rarely registers on their radar (Watkins and Sridhar 2019). Unlike other infectious diseases, pneumonia is not easily transmittable across social boundaries. Those most affected live in urban slums and impoverished rural areas and therefore, have far reduced potential for political mobilisation. While pneumonia has consistently been a top killer of children in LMICs, and its prioritisation on national agendas would be best for health equity and

reducing disease burdens, these factors rarely dictate political choice. Instead, specific diseases that impact interest groups and higher income urban populations are more likely to garner action than a disease that is poorly understood, affecting rural, impoverished, and isolated groups (Watkins and Sridhar 2019). These vulnerable populations with little influence and power have diminished priority when it comes to developing effective strategies that specifically target their health and wellbeing (Mechanic and Tanner 2007).

Perceptions of Threat

The second barrier to pneumonia prioritisation is its perception of threat on both a national and international scale. Pneumonia is not only socially contained within national borders but also poses no international transmittable risk for high-income countries. This is influential as international funding for diseases is highly dependent on perceptions of global health security and, as pneumonia can be contained to poor populations within poor countries, there is minimal global pressure (Brown and Head 2015; Watkins and Sridhar 2019). Further, pneumonia rarely registers on the minds of the general public as a top killer of children – malaria and diarrhoea are thought to factor more prominently (The Lancet Global Health 2018). This lack of attention from both macro- and micro-level health perspective amplifies the challenges of prioritisation.

Nationally, Ministries of Health in high-burden countries frequently do not have actionable pneumonia-related data and consequently, lack direction on what should be focused on given their local contexts, ultimately skewing the treat perception. While it is known generally how impactful pneumonia is on children's health, the lack of agency on the part of national governments leaves them at the mercy of external actors to dictate which disease are prioritized financially. All these factors have rendered pneumonia "a global cause without champions" (Watkins and Sridhar 2019, p718).

Complex Aetiology

Finally, pneumonia is complicated by the fact that its aetiology is multifaceted. The disease can result from an array of microbial infections meaning multiple causes, risk factors, and potential treatment options (Wahl et al. 2018). And, while most strains of pneumonia are treatable, there is no silver bullet that combats the multicausal nature of the disease making diagnosis challenging especially in low-resource settings (Watkins and Sridhar 2019).

Effective pneumonia interventions require an integrated health system that includes trained and resourced health workers, strategies to reduce health-related risk factors, and public health guidance on limiting air pollution. Universal health care is a necessary condition to achieving pneumonia reduction goals but alone is not enough. Developing national pneumonia plans with clear targets and detailed action plans that acknowledge the highlighted complexities of eradicating preventable deaths is equally vital. The complexity of the disease aetiology and the factors that influence its prevention make developing strategies particularly challenging.

2.3 Country Profiles

Nigeria, DRC, Ethiopia, India, and Pakistan are the five focus countries for this investigation. These countries were selected because they have the highest number of under-five pneumonia deaths, accounting for 49% of total deaths globally (Watkins et al. 2017; Mcallister et al. 2019). The section below outlines the basic demographics and child pneumonia incidence in each of the countries.

Nigeria

Nigeria is home to the largest population in Africa at just over 206.5 million people (UN 2019). The country has a growing population and high total fertility rate at an average 5.3 births per woman (The World Bank 2019). According to the National Population Commission in 2016, 41% of the Nigerian population were under-15 and 19% were under-five (National Bureau of Statistics 2018). The under-five mortality rate in 2018 was 132 deaths per 1,000 live births, 19% of which were due to pneumonia (National Population Commission 2018). Childhood pneumonia killed more than 162,000 children in 2018, equating to more than 18 children dying every hour (Watkins et al. 2017). The three largest risk factors cited for childhood pneumonia in Nigeria are: child wasting (51%), indoor air pollution (26%), and ambient air pollution (20%) (Save the Children 2020d). The proportion of children with pneumonia symptoms taken to a healthcare provider was relatively high in 2018 at 73% but this includes pharmacies that do not necessarily provide appropriate immediate care (Save the Children 2020d).

In order to meet the GAPPD targets, Nigeria must lower its child pneumonia deaths to approximately 26,000 per year by 2030. As the analysis below will confirm, at the current

trajectory (~2% annual rate of reduction), these goals will not be met until 2075 (Watkins et al. 2017).

DRC

DRC is an almost entirely landlocked country in Central Africa. Being home to a population of almost 90 million, its sizable landmass renders the population density relatively low at 35.9 people per km^2 (UN 2019). DRC has one of the highest fertility rates in the world at 6.11 births per woman resulting in the population growing at an average annual rate of 3.19% (UN 2019). The high fertility rate translates to a young population with a median age of 17 (DRC Ministère de la Santé Publique 2014). In 2018, the under-five mortality rate was 88.1 deaths per 1,000 live births (UN 2019).

In 2018, 72% of the population lived on less than $1.90 a day making DRC one of the most impoverished countries in the world (The World Bank 2020a). These high levels of poverty have affected not only the ability of the health system to function efficiently but has exposed millions to increased risk of 'diseases of poverty' like pneumonia. DRC is the only country included in this study where pneumonia deaths have increased by 11% from 1990 to 2017 (Greenslade 2018). In 2018, 11 out of every 1,000 under-five deaths were attributed to pneumonia making it the second highest killer of children in the country (Save the Children 2020a). The cited causal factors for childhood pneumonia in the DRC are wasting (55%), indoor air pollution (42%), and stunting (18%) (Save the Children 2020a). The proportion of children taken to a health facility for signs of pneumonia was low at 24% in 2013 (Save the Children 2020a). The average annual rate of reduction in childhood pneumonia mortality between 2000 and 2018 was 3% meaning that at this pace the 2025 GAPPD target would not be met until well after 2050.

Ethiopia

Ethiopia has a population of 115 million making it the second most populous country in Africa (UN 2019). The young age structure and high fertility rate per woman (4.1) results in the population growing at a rate of 2.7% annually (UN 2019). The 2019 Ethiopia Mini DHS shows that almost all child mortality rates have decreased since the previous survey years – under-five mortality falling from 87 to 55 deaths per 1,000 live births (Ethiopian Federal Ministry of Health 2019). Ethiopia's 71% decline in child mortality since 1990 has

been due to synergistic support between services, resources, and investments to increase the health, nutrition, and development policies within the country (Ruducha et al. 2015).

In 2018, pneumonia was the biggest killer of children, responsible for 17% of child deaths (Save the Children 2020b). It is estimated that 54% of child pneumonia cases are caused by wasting, 43%, by HAP, and 18% by stunting (Save the Children 2020b). Only 31% of children experiencing pneumonia symptoms were taken to a healthcare facility in 2016 (Save the Children 2018). The annual rate of reduction between 2000 and 2018 for child pneumonia deaths was 6% thus, at this pace, Ethiopia is expected to reach the 2025 GAPPD target in 2035 (Save the Children 2020b).

India

India spans 2.9 million km^2 and is home to almost 1.4 billion people, consequently on track to becoming the most populous country by 2024 (Ritchie 2019). Declining fertility rates in the last decade have resulted in the population growth slowing marginally - the total fertility rate in 2019 was just above replacement level at 2.2 children per woman (UN 2019). Based on the most recent family health survey, approximately 29% of the population is below 15 (IIPS 2016). The under-five mortality rate in India was 50 deaths per 1,000 live births in 2016 (IIPS 2016). The under-five mortality rate is considerably higher in rural areas and is highest in Uttar Pradesh State at 78 where children are twelve times more likely to die before five than in Kerala State where the under-five mortality rate is 7 deaths per 1,000 live births (IIPS 2016).

Over 127,000 children in India died from pneumonia in 2018 equalling more than 14 children an hour (Save the Children 2020c). It is estimated that 53% of child pneumonia deaths in India are caused by wasting, 27% by ambient air pollution, and 22% by HAP (Save the Children 2020c). The annual rate of reduction in pneumonia deaths between 2000 and 2018 was 7%, at this rate India is expected to reach the 2025 GAPPD target in 2026.

Pakistan

Pakistan has a population of approximately 221 million, 13% of which are under-five with the total fertility rate of 3.6 births per woman (UN 2019, NIPS 2019). The under-five mortality rate in 2018 was 74 deaths per 1,000 live births with the top three causes of death

being pneumonia, diarrhoea, and meningitis (IHME 2020). Pakistan's health indicators reflect the very poor status of child and maternal health in the country. A recent UNICEF report positioned Pakistan at the top of the list for newborn deaths as they face a 1:22 chance of dying within their first month (UNICEF 2019a). The weak health system, poor service delivery, inadequate nutrition, and low government spending on health contribute significantly to these high mortality rates (Agha 2018).

Ten out of every 1,000 under-five deaths in 2018 were a result of pneumonia, killing more than 58,000 children (Save the Children 2020e). The causal factors for child pneumonia in Pakistan are wasting (54%), HAP (22%), and ambient air pollution (21%). The average annual rate of reduction in pneumonia deaths between 2000 and 2018 was 4% meaning that Pakistan is set to reach the GAPPD target by 2044 given the current trends.

3. Conceptual Framework

This analysis conceptualizes childhood pneumonia within the broader context of the interaction between tandem causational vectors of health and wellness. The link has frequently been made between socioeconomic disadvantage at the population and individual level and rates of morbidity and mortality (Marmot and Wilkinson 1999; Graham 2000). While many studies have examined disease incidence via social influences, the relationship is not always explored in direct causal terms (Kelly et al. 2009; Cockerham 2007). What is frequently missing from pathogenic and salutogenic explanations are the positive and negative causes and effects of other branches of medicine and sociology on health (NICE 2012). Consequently, a model is required that traverses the traditional boundaries of coexisting disciplines in order to understand and develop effective interventions to improve health.

The conceptual framework that underpins this study was developed by the National Institute for Health and Clinical Excellence (NICE), a UK National Health Service partner. Through their role of producing evidence-based advice for health practitioners and developing quality standards and performance metrics, a conceptual framework was developed to inform future guidance (NICE 2020; Kelly et al. 2009; NICE 2012). This framework is centred on six core principles:

1. There are key determinants to health and disease other than biomedical considerations
2. These determinants impact individual level pathology and health differences within populations that reflect social inequalities
3. The determinants of health operate through causal pathways
4. These pathways help to identify ways of preventing diseases
5. The causal pathways can be used as a promotion of good health
6. The social, physical, biological, economic, and political boundaries are crossed by positive and negative causal pathways

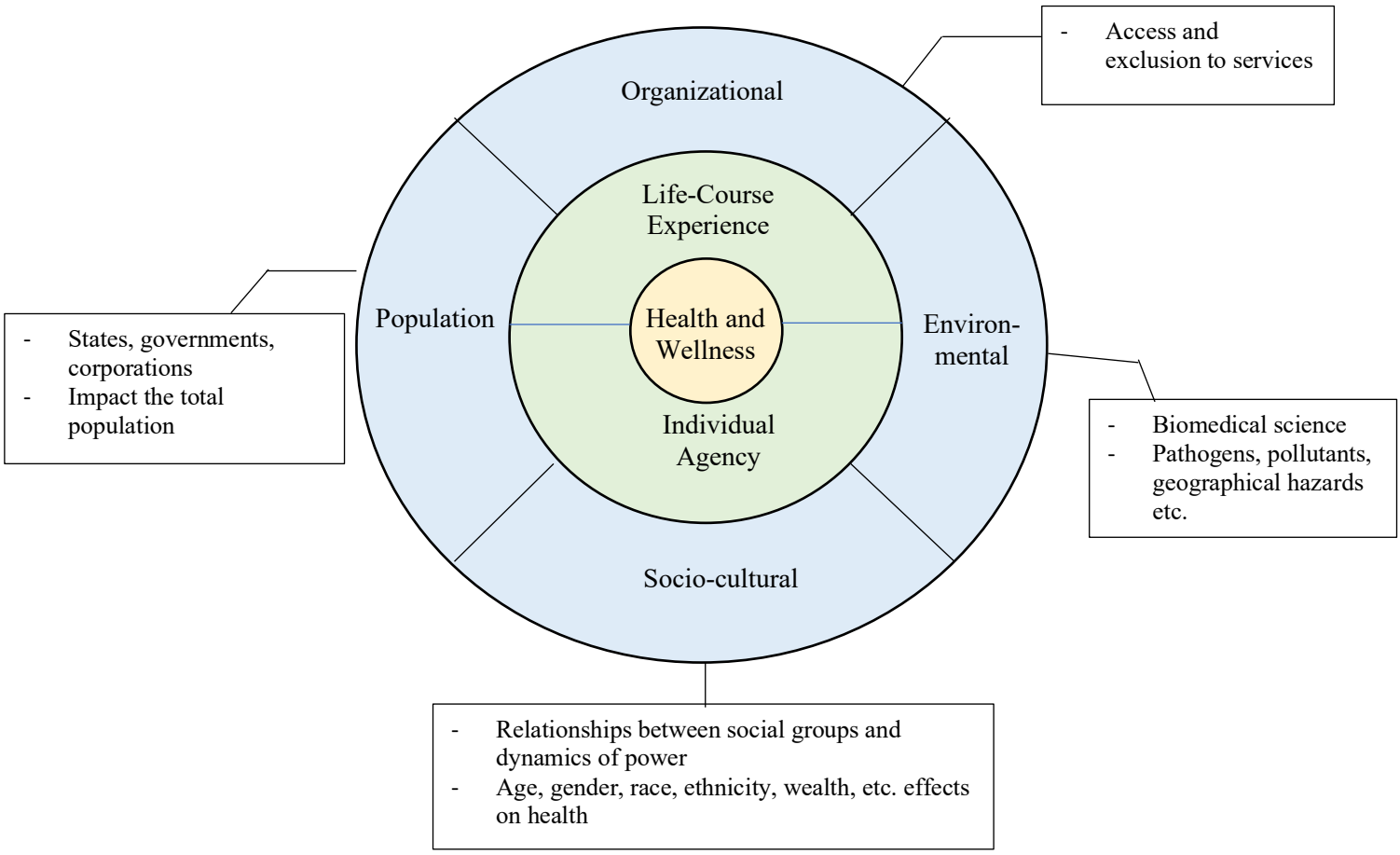

Figure 1: NICE (2012) framework for causal vectors of health and wellness; adopted from Kelly et al. 2009

The core of the framework is based on the link between economic, political, social, and biomedical phenomenon within four key vectors where the casual pathways of health and wellness operate: population, organizational, environmental, and socio-cultural. The inner circle represents the components of human behaviour that are a product of and impact on the

outer vectors (Figure 1). This conceptual framework is particularly beneficial because it distinguishes between the way social and biological factors influence individual instances of disease and how the two work in conjunction to cause disease patterns in a society (Kelly et al. 2009).

The social, political, biological, environmental, and demographic deterministic factors that go into not only pneumonia's incidence but how it is prevented and treated, prominence on the global health agenda, the funding it receives, public perception, and the relevant national and international policy has yet to be analysed within these contexts. By examining the intervention impacts through this lens there is hope that a more cohesive approach can be adopted in prevention strategies.

4. Methodology

4.1 Methods

Qualitative data analysis, grounded in relevant peer-reviewed literature, was deemed the most appropriate method for answering the proposed research question. For the purposes of this study, available data from Demographic Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MCIS) sources, as well as independent randomised-control trials (RCTs), were used to supplement the dataset within the modelling software.

A literature review was conducted in PubMed, Google Scholar, and EBMED in order to identify existing data and evidence relating to child pneumonia and effective preventative interventions. Grey literature including NGO publications, government reports, and policy documents were retrieved through Google search. Peer-reviewed articles and grey literature with pertinent evidence on the burden of the disease, causal factors, public health responses, and preventative programmes were collected from the last twenty years.

Although less tangible than curative interventions, preventative approaches were selected as the focus of the dissertation as they have the potential to build foundations for keeping children healthy and free of disease. Currently, care-seeking behaviour is the only recommended indicator for the measurement of pneumonia treatment within national surveys (UNICEF 2016). This is problematic because of the inability of many caretakers to identify symptoms resulting in inaccurate data on the number of children with true pneumonia who

are treated with antibiotics (Wardlaw, Johansson White, and Hodge 2006). Consequently, without reliable treatment data, and with the aim of approaching this dissertation more holistically, the focus is on pneumonia prevention. In addition, a preventative approach allows interventions to be targeted to country context rather than implementing blanket curative solutions that disregard the underlying cultural, socio-economic, geographic, and political contexts. The preventative interventions selected are based upon scientific evidence linking their effect on pneumonia incidence, feasibility of implementing or improving their coverage, and ensuring a range of interventions that address a wide spectrum of child health considerations.

Spectrum

This analysis used Spectrum v5.68 (2017) to model demographic changes as a result of select preventative pneumonia interventions. Spectrum is a policy modelling software made up of several modules that assists the user in analysing and planning health programmes (Bollinger et al. 2019). The software compiles national and regional health and demography data allowing for the projection of different scenarios based upon a series of assumptions and potential interventions. Country-specific data within the programme has been acquired and collated from pre-2017 national surveys. The most recent version of Spectrum accessible was 2017 and consequently, more up-to-date country-specific data was implemented where available.

The two modules used for this analysis are Demography Projection (DemProj) and Lives Saved Tool (LiST). DemProj calculations are based on the standard Cohort-Component Method modified to produce single year projections for a country or region based on assumptions about fertility, mortality, and migration (Bollinger et al. 2019). DemProj forms the demographic data basis for the other modules included in Spectrum.

LiST is a linear, mathematical model that produces changes in outcomes i.e. population risk factors, cause-specific mortality, and birth outcomes, based upon changes in coverage and efficacy of specific interventions (N. Walker, Tam, and Friberg 2013). LiST models these outcomes for maternal and child health programmes in order to assess which interventions would be most effective in increasing survival. The predominant assumption in LiST is that mortality rates and causes of death will not change except in response to changes

in intervention coverage (Bollinger et al. 2019). The software avoids double counting and inaccurate inflation by using cause-specific efficiency and applying each subsequent intervention to the residual deaths (N. Walker, Tam, and Friberg 2013). By using this module the effects of the prevention techniques individually, and within a larger package of interventions, on under-five mortality can be visualized.

A third module, AIDS Impact Model (AIM), is automatically included by Spectrum when LiST is used for countries with high rates of HIV/AIDS. AIM projects the consequences of the HIV epidemic on demographics and intervention impact. Because this analysis is not directly concerned with the impact of HIV/AIDS, the data already available in AIM was factored into intervention impact without modification.

The base-year of the projections was set to 2017 as this was the most recent dataset available in Spectrum that could be supplemented with the latest obtainable data. For baseline projections, the most recent data was duplicated to the end of the projection period as it was assumed that rates would remain constant in a 'no action' scenario. The intervention start year within LiST was set to 2020 and projected to 2030. While increasing the length of the projection period would have resulted in a broader picture of the long-term impacts of the prevention interventions, thee projections were kept within a shorter timeframe to improve accuracy and priority policy focus (Bollinger et al., 2019).

For each of the five countries, two scenarios were produced: baseline and intervention. The target intervention coverage rates were based on national or international goals and estimates established through literature reviews of each of the countries in order to determine feasibility (Table 1). All other variables in LiST not directly associated with preventing pneumonia were kept at their current levels in order to isolate the intervention effects.

Intervention	Target Coverage	Target Source
Zinc Supplementation	20%	*Estimation*
Vitamin A Supplementation	20% Increase	*Estimation*
Exclusive Breastfeeding for 6 mo.	70%	Global Breastfeeding Collective 2030
Complementary Feeding	30% Increase	*Estimation*
Clean Cooking Fuels	31% - Nigeria, DRC, Ethiopia 43% Increase – India, Pakistan	Africa Agenda 2063; *Estimation*

Hib Vaccine	90% National Programmes	Global Vaccine Action Plan 2020
Pneumococcal Conjugate Vaccine (PCV)	90% National Programmes 80% Sub-National Programmes – India	

Table 1: LiST Intervention Coverage and Source

The default effectiveness values for the interventions are set in Spectrum and based on rigorous scientific study thus were not altered for this analysis with the exception of clean cooking fuels which was a custom intervention (Bollinger et al. 2019). In order to develop the custom intervention, clean cooking fuels were identified as a preventative intervention and the effectiveness value was set to 0.450 in keeping with HAP effect on pneumonia rates and country-level studies on the topic.

4.2 Interventions

Below is a description of each of the interventions and evidence supporting its link to pneumonia prevention as well as the target coverage increase implemented within LiST.

Zinc Supplementation

Zinc is an essential micronutrient for human development, existing in every living organism and contributing to DNA synthesis and cell differentiation (C. F. Walker and Black 2004). The role of zinc in growth, reproductive function, and immuno-competence is well understood as are the significant negative consequences of zinc deficiency particularly for children (Lassi, Moin, and Bhutta 2016; C. F. Walker and Black 2004; Hotz and Brown 2004). Zinc deficiency impairs the body's ability to fight off infection by supressing essential production of key antibodies. Strong evidence from RCTs in LMICs has emerged since the late 1980's for a causal relationship between zinc supplementation and improved immune function against childhood infections including diarrhoea and LRIs (Black et al. 1999). There are no bioavailable or functional markers to identify zinc deficiency, making identification of the extent of the issue, as well as effective interventions to target it, significantly more challenging (Z. Bhutta et al. 2013).

The relationship between zinc supplementation and pneumonia incidence has been widely studied both in terms of preventative supplementation and therapeutic treatment. The Zinc Investigators Collaborative Group conducted a pooled analysis of zinc supplementation RCTs and pneumonia incidence and found that children who were supplemented had a 41%

reduction in incidence (Hotz and Brown 2004; Z. A. Bhutta et al. 1999). Similarly, a study in Bangladesh gave children 2-12 months weekly zinc supplements for a year and found that in comparison with the placebo group, those children who had received zinc experienced significantly lower incidence of pneumonia and a reduced pneumonia-mortality rate (Brooks et al. 2005). However, other studies report that the effects of supplementation on pneumonia prevention are statistically insignificant and that there is insufficient evidence supporting universal supplementation (Out et al. 2014). This heterogeneity suggests the need for a continued exploration of this relationship.

For the purposes of this analysis, zinc supplementation is defined in keeping with Spectrum as 10mg/day for children 12-59 months. For each country, baseline supplementation rates were set to 0 as national health surveys do not typically quantify this data. As such, zinc deficiency rates were estimated based on relevant academic literature for each country.

For the goal projections, supplementation rate was set to 20% by 2030 and interpolated back to the first year of intervention. This percentage was chosen based on aggregate zinc deficiency rates and realistic targets for national programmes in the five countries.

Vitamin A Supplementation

It is estimated that 250 million preschool-aged children have a vitamin A deficiency (VAD) (WHO 2018b). As the leading cause of preventable blindness and a significant risk factor for death from severe infections, VAD has been a prominent public health concern for international health providers. The WHO has estimated that in 2013 VAD affected one third of children globally with the highest rates being in Sub-Saharan Africa (48%) and South Asia (44%) (WHO 2019d). A global risk factor assessment estimated that VAD is responsible for 1.8% of the global burden of diseases (Bahreynian et al. 2017; IHME 2017). Vitamin A is an essential micronutrient for growth, cell proliferation, reproductive capacity, and the development of tissue (Bahreynian et al. 2017). Biannual supplementation is a proven intervention to reduce under-five mortality between six months and five years (Horton et al. 2008). Despite years of progress in increasing coverage rates for supplementation globally, in 2018, programmes dropped to a six year low (UNICEF 2018).

Because of vitamin A's role immune cell production, supplementation has been shown to reduce the potentially deadly outcomes associated with pneumonia (WHO 2011). Pre-existing deficiency seems to worsen infections and supplementation has been shown to reduce the risk of death for children 6-59 months by 20-30% (Pnasziou and Meackerras 1993). However, it is hypothesised that an excess of the micronutrient may cause a temporary malfunction in the immune system making the host more susceptible to pathogens (WHO 2011). Consequently, supplementation for children with poor nutritional status may be the best approach to prevent instances of childhood pneumonia.

Spectrum calculates the effect of vitamin A coverage increase for children 6-59 months receiving a biannual dose. The baseline projections employ data from UNICEF on rates of supplementation coverage and estimates were made for a 20% increase in coverage for each country's goal projection scenario. A 20% increase was selected because this would result in a 2% annual increase in coverage until 2030, which is in line with the trends in coverage prior to the rates dropping.

Breastfeeding

Optimal nutrition, including appropriate breastfeeding practices, within the first thousand days of life drastically lowers a child's rate of morbidity and mortality, reduces risk of acute and chronic diseases, and has significant positive impact on growth and development (Imdad, Yakoob, and Bhutta 2011; WHO 2020c). The WHO and UNICEF recommend early initiation of breastfeeding within one hour of birth, exclusive breastfeeding for the first six months, and the introduction of appropriate complementary foods at six months along with breastfeeding until at least two (WHO 2020c). These guidelines for optimal breastfeeding, if followed correctly, have the potential to save the lives of over 820,000 children under-five annually (WHO 2020c; Lancet 2016). Breastmilk contains large amounts of secretory immunoglobulin A, antibodies developed by the mother from previous exposure to infectious agents that can bind to potential pathogens in the infant and reduce instances of disease (Jackson and Nazar 2006). This relationship between breastmilk and immune response has been particularly focused on in reference to reducing instances of childhood diarrhoea but has been cited to protect against other infections (Jackson and Nazar 2006; Lancet 2016). In 2017, an estimated 41% of children globally were exclusively breastfed for the first six

months of life (WHO 2019b). While an encouraging improvement from previous years, three in five children still are not attaining the maximum benefit from appropriate feeding practices, particularly in East Asia/Pacific and Middle East/North Africa where rates have persisted around 30% (WHO 2019b).

Without suitable nutrients from breastmilk children are susceptible to higher rates of morbidity and mortality from pneumonia (Ginsburg et al. 2015). It has been estimated that 595,379 diarrhoeal and pneumonia deaths between the ages of 5-59 months annually can be attributed to not breastfeeding according to recommendations (Walters, Phan, and Mathisen 2019). In addition to the immune-boosting functions of breastmilk, the alternative options for child feeding increases the risk of contracting viral and bacterial strains of pneumonia. For example, in Ethiopia it is estimated that 5 million cases of pneumonia and diarrhoea in children under-five can be attributed to a lack of appropriate breastfeeding leading to a weakened immune system and a reliance on unsafe drinking water (Alive & Thrive 2020a). The number of cases attributed to poor breastfeeding practices reaches as high as 37 million in India among the countries selected for analysis (Alive & Thrive 2020b). The protective effects of breastfeeding against child pneumonia incidence, prevalence, hospitalization, and mortality makes it one of the most cost-effective and efficient prevention strategies for LMICs (Lamberti et al. 2013).

The goal scenario for projections were set in line with the Global Breastfeeding Collection 2030 goal of 70% of children exclusively breastfeed for the first six months of life (Global Breastfeeding Collective n.d.). This analysis did not assess the impact of breastfeeding promotion but, given the low rates of exclusive and continued breastfeeding in several of the countries studied, such research is warranted.

Immunization

Vaccines are a cost-effective and highly efficacious way of preventing illness (Oliwa and Marais 2017). In LMICs, the uptake of routine vaccination increased dramatically with the creation of the Global Alliance for Vaccination and Immunization (GAVI) in 2000 (Oliwa and Marais 2017). By 2013, routine vaccinations were estimated to have averted six million deaths from vaccine-preventable diseases (WHO 2020a). Immunization is perhaps the most successful public health programme, reaching approximately 85% of infants in 2019

(UNICEF and WHO 2020). Despite this impressive statistic, immunization rates have plateaued in the last decade - most of this stagnation occurring in the African Region. Just ten countries account for 62% of the unprotected children – five of these countries are those selected for this analysis (UNICEF and WHO 2020). There are various explanations for a drop in rates including limited access due to conflict, countries phasing out of GAVI support, vaccination apprehension, financial constraints, and more recently, the COVID-19 pandemic. While data is still emerging on the effects of the pandemic on immunization rates, preliminary data suggests that there have been steep drops in the number of doses administered globally. Impacted service delivery, physical distancing, self-isolation, and restricted transportation services all play a role in these changes. The two vaccinations selected for this analysis are PCV and Hib as they prevent against the two leading bacterial causes of pneumonia (Wahl et al. 2018).

High-valency PCV vaccines are now routinely used because they protect from a greater number of strains depending on the prevalence within the region in question. After the WHO recommended the inclusion of PCV into national vaccination programmes in 2007, 103 countries had implemented these vaccinations by 2013, although coverage was still low at approximately 25% (Oliwa and Marais 2017). Current coverage of PCV globally stands at 48% for the full three doses required (WHO 2020b).

The Hib vaccine efficacy is reported to be 94% for two doses, dropping down to 38% with only one dose (Griffiths et al. 2012). Guidelines now recommend three doses, which are frequently administered in a pentavalent vaccine (Madhi et al. 2013). Global coverage of a three dose Hib vaccine is estimated to be 72% (WHO 2020b).

Baseline vaccine coverage rates were attained from 2019 WHO data and the goal scenarios were set to 90% coverage for national programmes and 80% for regional programmes for both PCV and Hib vaccinations in line with the Global Vaccine Action Plan. The target year for the 2011 Action Plan was 2020, but because coverage rates are yet to reach the target, this analysis has maintained the same coverage goals for 2030.

Malnutrition

While malnutrition encompasses both over- and under-nutrition and a lack of essential micronutrients, the primary foci for analysis are the effects of wasting (acute malnutrition) and stunting (chronic malnutrition) as risk factors for childhood pneumonia. It is estimated that undernutrition is implicated in approximately 45% of under-five deaths globally (WHO 2019a). In 2019, 47 million children under-five were wasted, 14.3 million were severely wasted, and 144 million were stunted (WHO 2020d). While progress has been made in reducing these rates - a 70% and 34% decrease in wasting and stunting prevalence respectively - the burden still remains overwhelming (WHO 2020d).

Malnourished children, especially those with severe acute wasting, have a much higher risk of contracting and dying from common childhood infections including pneumonia (Walson and Berkley 2018). Lack of proper nutrients weakens the immune system and renders the body unable to fight off infection effectively. In the case of pneumonia, undernutrition weakens the respiratory muscles making clearing secretions from the respiratory tract significantly more challenging (UNICEF 2012). It is estimated that there is a two to three times greater risk of a child dying from pneumonia if they are suffering from a malnutrition related co-morbidity (Elsayh et al. 2013).

For the purposes of the LiST projections, complementary feeding for the reduction of stunting and wasting were used as proxies for preventative interventions. Due to skewed results in initial testing using direct input of targets, the results garnered from the proxy measures were more in-line with previous research. Complementary feeding was increased by 30% for the goal projections.

Air Pollution

Approximately 2 billion children under-18 live in areas where the outdoor air pollution far exceeds the international guideline limits of 10 micrograms per cubic meter of particulate matter less than 2.5 micrometres ($PM_{2.5}$) annually (Ritchie and Roser 2019). PM is often used as a proxy for air pollution as it affects more people than any other pollutant (WHO 2018a). In 2016, over 90% of premature deaths caused by air pollution occurred in LMICs, especially in South-East Asia and the Western Pacific (WHO 2018a). Because children inhale more oxygen per unit body weight than adults they are particularly

susceptible to PM pollution which can have an impact on their long term lung and immune system development (Thi et al. 2017).

Around half of child pneumonia deaths are associated with air pollution (UNICEF 2016). And, while outdoor air pollution is a significant contributing factor for pneumonia incidence, HAP via improving reliance on clean cooking fuels, was selected as the focus for this preventative intervention. The justifications for this selection are manifold: HAP is one of the leading causes of child LRI deaths; HAP from cooking is responsible for 12% of global ambient $PM_{2.5}$, causing half a million air pollution-related deaths; and HAP reduction interventions are more easily implemented, targeted, and tracked than those which impact outdoor air pollution (Smith et al. 2000; Dherani et al. 2008; Thi et al. 2017).

HAP contains a number of health-damaging toxins including $PM_{2.5}$ which can penetrate the lungs and bloodstream and trigger inflammation and oxidative stress leading to pneumonia, lung cancer, COPD, and cardiovascular distress (WHO 2016). Women and children are at particularly high risk for morbidity and mortality caused by HAP, representing over 60% of premature deaths (WHO 2016). Increased exposure stems from women spending more time cooking and with children at home. Relatively small reductions in $PM_{2.5}$ from clean cooking technologies decrease the risk of childhood pneumonia by a minute amount, meaning that substantially cleaner technologies are required to result in lowered incidence rates (WHO 2016). These priorities have been reflected in the SDGs as Goal 7 calls for universal access to “affordable, reliable, sustainable, and modern energy” by 2030, as measured by the percentage of people primarily relying on clean cooking fuels and technology (UN 2019).

Conflicting evidence on the efficacy of clean cooking fuels in reducing incidences of pneumonia led to a re-calculation of intervention impact data, using a 0.450 efficacy rate rather than 0.600. The result of this change was a reduction in the number of lives saved by the implementation of cleaner cooking fuels but likely reflects the inconsistent evidence on the topic. This efficacy rate was used for both neonatal and 1-59 month age groups as it was challenging finding studies that disaggregated the effects by age. Clean cooking fuel targets were scaled-up for the goal scenario based on regional goals.

4.3 Limitations

There are three primary limitations to this study: the availability of reliable and complete data, the feasibility of the selected interventions given the country contexts, and the proxy nutrition interventions employed. The most significant limitation is the quality and availability of data as it determines the outcome of the projections as well as the impact of the proposed interventions. By relying primarily on DHS data there is likely missing or incomplete information that is not included in the dataset, including limited coverage of specific subsets of the population. This is particularly pertinent to this study as a large majority of pneumonia-related child deaths occur among the most impoverished populations who are often challenging to account for. This limitation was somewhat mitigated for by cross-checking national data with other independent studies where possible.

The second limitation is the feasibility of the proposed interventions. While a complete review of the acceptability of each of the seven interventions in all five of the countries selected is beyond the scope of this dissertation, the lack of detailed analysis into these considerations is a drawback of the research. Effective interventions are not solely dependent on their physiological impact on disease rates but also how these interventions are viewed by the communities implementing them, how they are going to be paid for, the availability of necessary resources, and any positive or negative externalities that emerge from their inception. Through the research design and literature review processes considerations were made for these challenges and interventions were selected for their effectiveness at preventing pneumonia, feasibility of effective implementation, and availability within the modelling software.

The third limitation is the proxy measure of malnutrition used within the calculations of intervention impact. The background literature proposed that wasting is a significant risk factor for pneumonia incidence. However, this analysis shows that increasing the prevalence of complementary feeding via a reduction in stunting or wasting has very limited impact on under-five pneumonia morality. While LiST allows for a direct entry of wasting and stunting within a given population, the software does not allow for easy projected target setting to change these rates. As such, a proxy of complementary feeding prevalence was selected. These values are likely underestimated as a result. Preventative interventions for childhood malnutrition are multifaceted and taking account of all these factors would be beyond the

scope of this dissertation. More accurate projections likely would have been produced if all these factors were taken into account.

5. Results

The section below outlines the results of the LiST projections under both baseline and goal scenario assumptions for each country. Additional findings and graphical representations of the data can be found in the Appendix section.

Nigeria

At the intervention start year, the primary cause of death for children under-five was pneumonia, killing an estimated 152,523 children in 2020. Pneumonia remains the largest killer at 10% of under-five deaths in the 2030 goal scenario, a reduction from 14% at the baseline 2030 projection. Between 2020 and 2030, the interventions responsible for the highest percentage of additional lives saved by cause are Hib vaccination (33%) followed by clean cooking fuels (31%) and PCV (22%) (Figure 2). While the vaccination rates of both Hib and PCV are low at 57% (National Population Commission 2018), the higher impact of the Hib vaccine is due to its greater effectiveness value in reducing childhood pneumonia incidence. Vitamin A supplementation and complementary feeding via reduction in wasting have a statistically insignificant impact on additional child lives saved in Nigeria. Due to the scale-up of interventions in the goal scenario, it is projected that 273,192 child lives will be saved from pneumonia in the 10-year intervention time period. The baseline projection shows an average annual death rate from pneumonia between 2020-2030 at 178,883; with the scale-up of interventions the annual death rate drops to 154,497. Even with the scale-up of the seven interventions, the annual death rate due to pneumonia (14 per 1,000) in Nigeria is still too high to be able to reach the GAPPD targets within the designated timeframe.

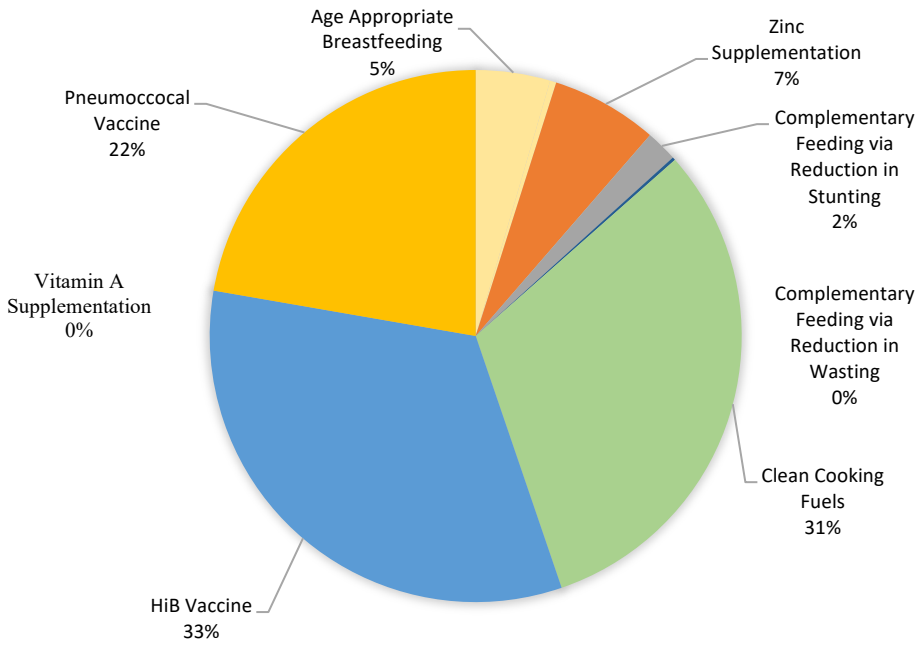

Figure 2: Nigeria Additional U5 Child Lives Saved from Pneumonia by Intervention (%) 2020-2030, Goal

DRC

Pneumonia was the second largest killer of children, responsible for 42,340 child deaths in the baseline 2020 projection. Pneumonia remains the second largest killer for the goal projection but is reduced by 2% - saving an estimated 53,233 children between 2020 and 2030. Clean cooking fuels (52%), Hib vaccination (22%), and zinc supplementation (15%) are the three preventative interventions that result in the highest percentage of additional lives saved by cause (Figure 3). These results are unsurprising as rates of reliance on clean cooking fuels currently stands at 3% nationally (IEA 2019a) making the increase to a 31% reliance rate substantial. DRC has relatively high rates of vaccination for PCV (81%) and thus an increase to 90% coverage makes less of an impact. An estimated 82.5% of children in the country are zinc deficient (DRC Ministère de la Santé Publique 2014) which explains the substantial impact of supplementation programmes on pneumonia incidence. Vitamin A supplementation and complementary feeding via reduction in wasting save an additional 186 and 38 lives by cause respectively making them statistically insignificant. In the case of DRC, the goal of increasing exclusive breastfeeding for the first six months to 70% was not relevant as rates are already high at 78% (DRC Ministère de la Santé Publique 2014). The under-five mortality rate decreases from 104 in 2020 to 94.92 per 1,000 in 2030 as a result of the interventions. Overall, the scale-up of interventions saves 47,323 additional child lives from

pneumonia. Between 2020 and 2030, under the baseline assumptions, the average annual death rate due to pneumonia is 50,574; for the goal scenario this number drops to 46,151. The pneumonia death rate under the goal scenario is 9.7 per 1,000, compared to 11 per 1,000 under baseline conditions. Consequently, even with these interventions, DRC would be significantly off track to meet the GAPPD targets by 2030.

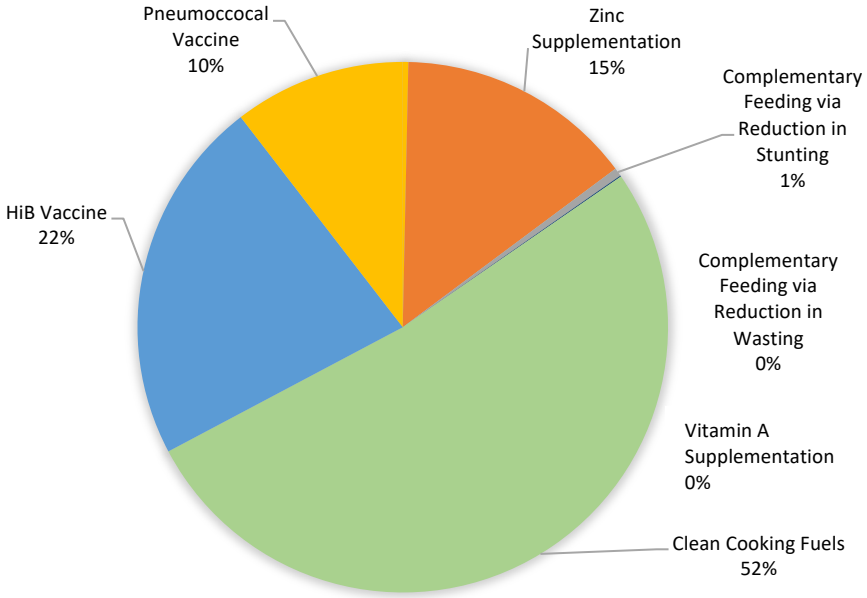

Figure 3: DRC Additional U5 Child Lives Saved from Pneumonia by Intervention (%) 2020-2030, Goal

Ethiopia

The baseline results support the literature that pneumonia is the biggest killer of children under-five in Ethiopia, responsible for a projected 18,775 deaths in 2020. The goal scenario reduces this projection to 14,431 deaths in 2030, saving 4,813 lives compared to the baseline status quo being maintained to the end of the projection period. Neonatal deaths make up a significant percentage of total under-five deaths in Ethiopia and, while the country has made remarkable progress in decreasing these mortality rates, in part due to the implementation of the National Child Survival Strategy (2005-2015), neonatal mortality rate has declined more slowly (Tekelab et al. 2019). The proposed interventions for this analysis have less of an impact on neonatal mortality rates because of the age of vaccination and supplementation. The interventions that do show the greatest impact on under-five mortality are age-appropriate breastfeeding (29%), clean cooking fuels (26%), and Hib vaccination (21%) (Figure 4). Rates of exclusive breastfeeding are relatively high for the first month of life at 73% but decrease to 54% between 1-5 months of age (Ethiopian Federal Ministry of

Health 2019). Consequently, increasing this rate to 70% for the 1-5 month age group by 2030 makes a substantial impact. The effect of an increased reliance on clean cooking fuels is unsurprising given an estimated 84% of Ethiopians use solid biomass fuels for cooking and only 7% have access to clean cooking fuels (IEA 2019b). Complementary feeding via a reduction in wasting and stunting both had a 2% impact on the total, likely because rates of complementary feeding were very low at 13% at baseline. In total, the six interventions that impact pneumonia rates in Ethiopia had a cumulative effect of saving 29,424 additional child lives and reducing under-five mortality rate from a projected 54 in 2030 under baseline assumptions to 52 per 1,000 under goal assumptions. However, the pneumonia death rate still remains higher than the target value in 2030 at 4.2 per 1,000 live births.

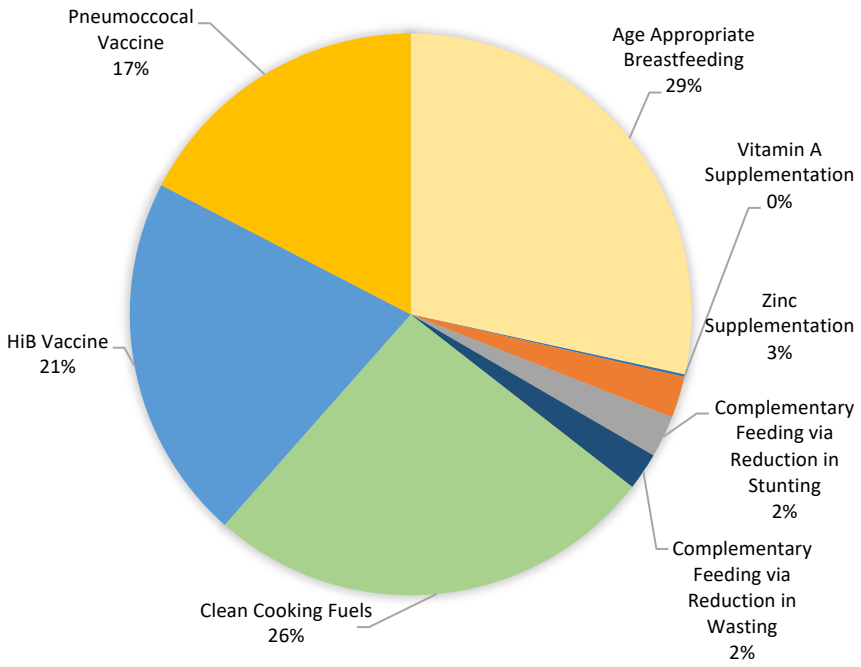

Figure 4: Ethiopia Additional U5 Child Lives Saved from Pneumonia by Intervention (%) 2020-2030, Goal

India

In 2020, an estimated 130,378 children will lose their lives from pneumonia in India, making it the second leading cause of death for children under-five. The 2030 projections for both the baseline and goal scenarios show that pneumonia remains the largest killer of children 1-59 months and the second largest killer of children under-five after neonatal preterm birth complications. The goal 2030 projection shows the number of pneumonia deaths at 82,810, substantially lower than the projected 123,057 for the baseline 2030 scenario. The three prevention interventions with the greatest impact on under-five mortality

in India are: PCV (32%), clean cooking fuels (32%), and age-appropriate breastfeeding practices (28%) (Figure 5). Because PCV is not yet offered in the national vaccination schedule for children, increase to 80% coverage from 6% in 2018 is dramatic. While seemingly infeasible given the current rates of vaccination, this target for PCV is attainable as the Government of India, in partnership with GAVI, are phasing in national coverage over the next several years (Ministry of Health & Family Welfare 2017). Other nationally implemented vaccinations have rates of almost 90%, boding well for the impact of PCV. While the availability of clean cooking fuels is estimated to be around 49% in India, the reliance remains much lower (IEA 2019). Due to a lack of reliable data on these rates, the 49% value was used for the projections resulting in a 70% coverage rate for this intervention. This likely over estimates the feasibility of reaching this target but shows just how impactful clean cooking fuels have on pneumonia rates. The majority of additional lives saved by the interventions are represented within reductions in pneumonia deaths at 171,040. Out of the five high-burden countries, India is the closest to reaching the GAPPD targets. The pneumonia death rate is estimated to be at 3 per 1,000 live births by 2030 – on target though five years late.

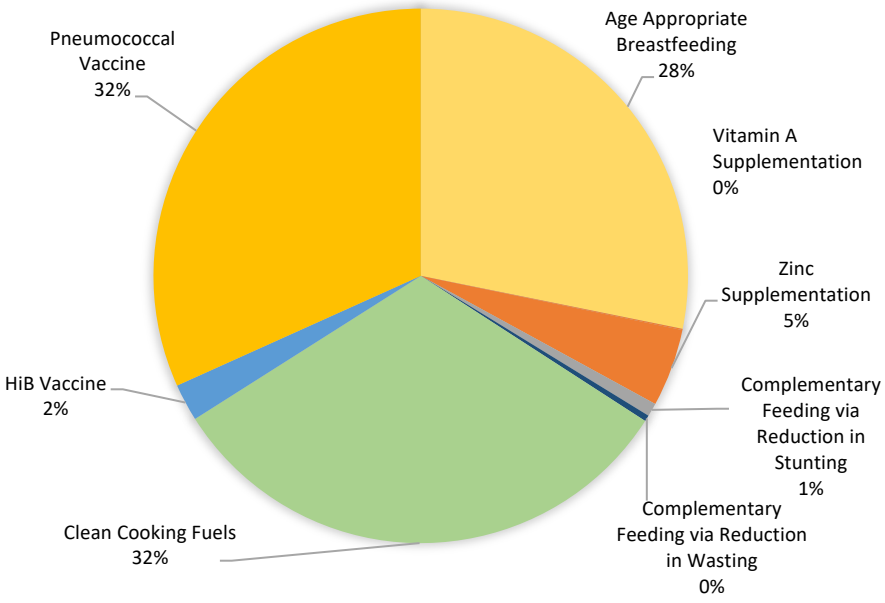

Figure 5: India Additional U5 Child Lives Saved from Pneumonia by Intervention (%) 2020-2030, Goal

Pakistan

The results of the baseline projections show 34,305 children dying from pneumonia in 2020. Over the ten-year period, given the current trajectory of the baseline scenario, a total of 392,368 children could be killed by the disease. Pneumonia deaths decrease from 5% to 4% of total deaths given the interventions implemented. The three interventions with the greatest impact on under-five mortality are Hib vaccination (37%), clean cooking fuels (35%), and age-appropriate breastfeeding (13%) (Figure 6). These three interventions alone save an additional 20,109 lives over the ten-year projection period. The total additional lives saved from pneumonia as a result of the cumulative impact of the interventions is 67,676. Hib vaccination rates in Pakistan are relatively high at 75% but given its high effectiveness value the increase in coverage makes a large impact. Surprisingly, age-appropriate breastfeeding does not have as dramatic of an impact as expected given the current rates of exclusive breastfeeding in the first six months at approximately 45% (NIPS 2019). 61% of the lives saved by the selected interventions are from pneumonia. In 2020 the pneumonia death rate is estimated to be 6 per 1,000 live births, if nothing changes this rate will remain in the 2030 projection. As a result of the interventions, the pneumonia death rate drops to 4.9 per 1,000 in 2030. While still not at the GAPPD target, the progress in decreasing the mortality rates will likely accelerate the time span it takes Pakistan to reach these goals.

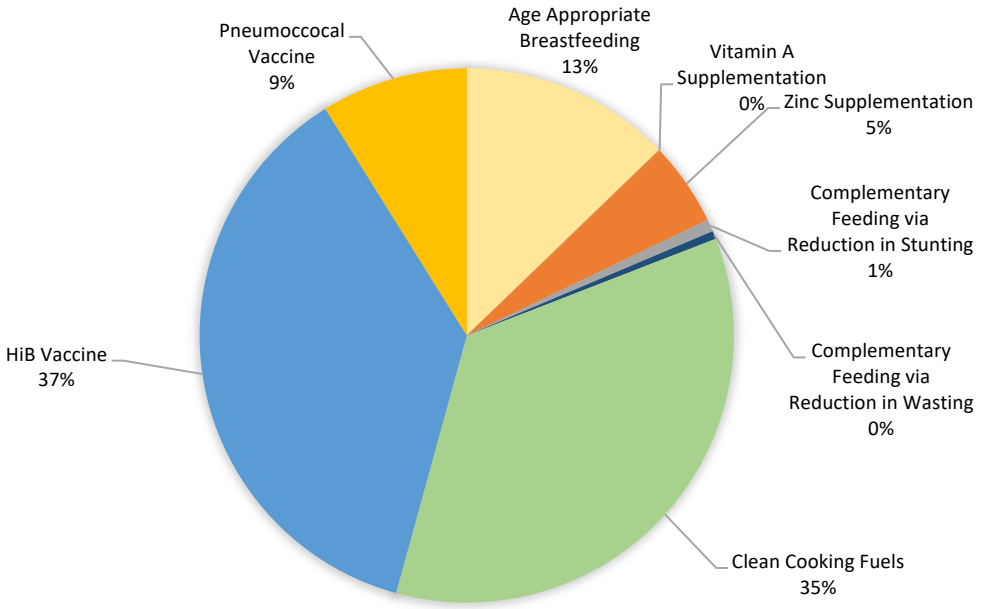

Figure 6: Pakistan Additional U5 Child Lives Saved from Pneumonia by Intervention (%) 2020-2030, Goal

6. Discussion and Conclusion

This analysis used LiST to simulate potential child lives saved by scaling up pneumonia prevention interventions in Nigeria, DRC, Ethiopia, India, and Pakistan. The results show that the most effective interventions in the majority of the five countries studied in reducing under-five pneumonia mortality are clean cooking fuels, Hib vaccination, and age-appropriate breastfeeding. The impact of clean cooking fuels and targeted vaccinations on the relationship between under-five mortality and pneumonia is supported by the findings of this research. Priority should be placed on ensuring that national policies for reducing HAP and ambient air pollution are followed and partnerships are made with key stakeholders in order to give countries the greatest opportunity for success in meeting the proposed targets. Interestingly, while the literature suggests that child wasting has a significant impact on mortality due to pneumonia, this analysis shows limited child lives saved by the scale-up of targeted interventions. This potentially is due to the proxy of complementary feeding used within LiST. Because this analysis centres on preventative interventions and wasting is an acute condition, curative interventions would have a greater impact on wasting as a risk factor for pneumonia deaths.

Vitamin A seems to have a greater impact on the reduction of overall mortality, as the results show between a 2% and 8% effect on additional lives saved by intervention depending on the country. While supplementation alone may not have a significant impact on pneumonia death rates, a reduction in the incidence of other conditions, namely diarrhoea, can reduce the risk factors for contracting the disease. As such, this intervention should not be deemed completely ineffective. Similarly, zinc supplementation has been shown to be an effective diarrhoea treatment and is particularly effective in reducing under-five mortality risks from pneumonia in areas where children are substantially zinc deficient. Zinc supplementation has also been proven to be an effective intervention to tackle stunting and consequently, reduces two malnutrition-related risk factors for pneumonia (Imdad and Bhutta 2011; Umeta et al. 2000; Moschovis et al. 2015).

Intervention	Additional Child Lives Saved 2020-2030
Clean Cooking Fuels	170,434
PCV	118,116[1]
Hib Vaccine	107,174
Age-Appropriate Breastfeeding	68,179
Zinc Supplementation	32,876
Complementary Feeding (via reduction in stunting)	6,887
Complementary Feeding (via reduction in wasting)	1,728
Vitamin A Supplementation	1,253
Total	**506, 647**

Table 2 shows the additional lives saved from pneumonia by intervention among the five countries studied. In total, a projected 506,647 child lives could be saved over the 10-year period if each of these interventions were implemented at the target rates. It is estimated that 735,000 children will die from pneumonia in 2030 (Watkins et al. 2017) but, with the proposed interventions and the resulting lives saved, this number could be reduced to 228,353.

It became clear through the research process and data analysis just how dependant mortality rates due to pneumonia are on the contextual environments in which they exist. While this socio-cultural-pathological link is not unique to this disease, the position that pneumonia has historically occupied on the global health agenda has exacerbated its impact on under-five mortality rates. Through this framework, and by means of lessons learned from previous failures to target this preventable disease and others like it in LMICs, there emerges a need to divert from temporary solutions to ones that involve deep investments in health systems. Progress towards implementation of Integrated Management of Childhood Illness guidelines in many of these countries is a good step towards horizontal management of comorbidities but, as the NICE framework illustrates, environment and biological factors are just part of the larger picture.

[1] Prominent effect due to low baseline PCV rates in India

In the case of pneumonia, an acknowledgement of the systematic neglect of vulnerable populations, lack of political pull in influencing national strategy, power imbalances between social groups, and promotion of individual agency are all required in conjunction to target pneumonia. As mentioned previously, the factors that have historically left pneumonia off the global health agenda continue to impose barriers on the effective implementation of intervention programmes. Currently, high-burden countries are at the whim of the global agenda, lacking the agency to prioritize health concerns that are pertinent to their citizens. Examples do exist of national governments taking progressive action - in 2019, the Nigerian Federal Government instated the Nigerian Pneumonia Control Strategy and Implementation Plan. The goal of this plan is to adopt an integrated approach to protection, prevention and treatment and, most importantly, symbolizes a recognition of childhood pneumonia as a major public health concern. Rather than a siloed approach, this plan sets out strategies for the national government and health sector to create a coalition with key partners and stakeholders to horizontally strengthen the healthcare approach (Nigerian Federal Ministry of Health 2019). In addition, the establishment of the GAPPD and the targets outlined within it have spurred a modicum of action against pneumonia and diarrhoea but, as this analysis shows, they are unrealistic within the timeframe proposed for all the countries studied. Further research into the necessary scale-up of preventative interventions to meet the GAPPD targets by a certain year would be worthwhile.

As the global health community, and the world as a whole, grapples with the challenges of a pervasive public health pandemic, COVID19 presents opportunities for pneumonia. A severe complication of COVID19 is viral pneumonia and, while less common than bacterial strains, can be equally as life-threatening. The consequences of this added burden on countries that are already struggling under the weight of high pneumonia death rates are yet to be fully understood but are likely to be substantial. The WHO have pledged $2 billion towards relief efforts and research into the disease while the World Bank has made available $12 billion in immediate support for countries to cope with health and economic impacts of the pandemic (The World Bank 2020b). The hope is that in the wake of this virus, greater attention will be paid to the devastating consequences of pneumonia not only for children but through the life cycle. The increased funding going to respiratory conditions and treatment options will be particularly impactful in LMICs were health systems are frequently under-resourced with key lifesaving treatments such as supplemental oxygen (Watkins et al. 2017). In the coming years it will be interesting to analyse the impact COVID19 has had on

both pneumonia incidence and, further down the line, prominence placed on the disease within global health discourse.

In conclusion, the interventions selected for analysis do have a substantial impact on under-five mortality in high-burden pneumonia countries. The importance of focusing on country-specific strategies cannot be understated given the complexity of variables and considerations that must be made for effective preventative interventions. Pneumonia is preventable, and, with buy-in from the international community and national governments and multi-faceted interventions across socio-cultural, environmental, population, and organizational spheres, great reductions can be made in morbidity and mortality.

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8. Appendix

Appendix 1: Causes of Death Under-five, Baseline 2030

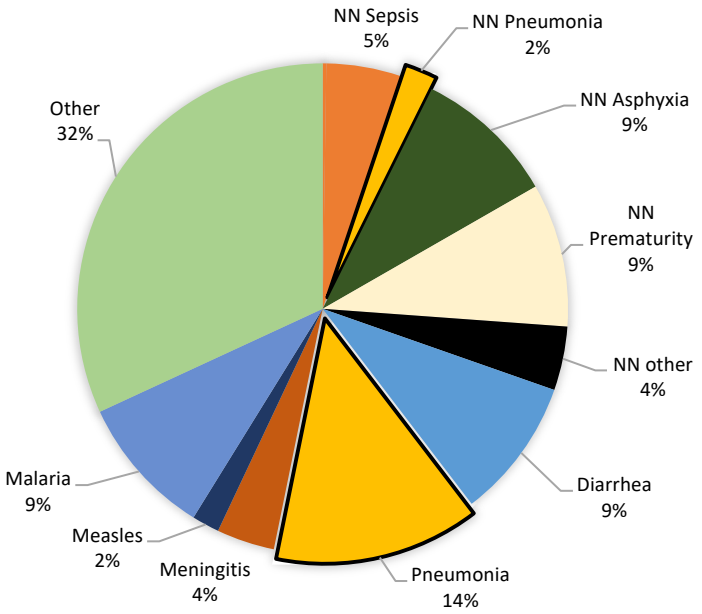


Figure 1: Nigeria Under 5 Cause of Death (%) 2030, Baseline

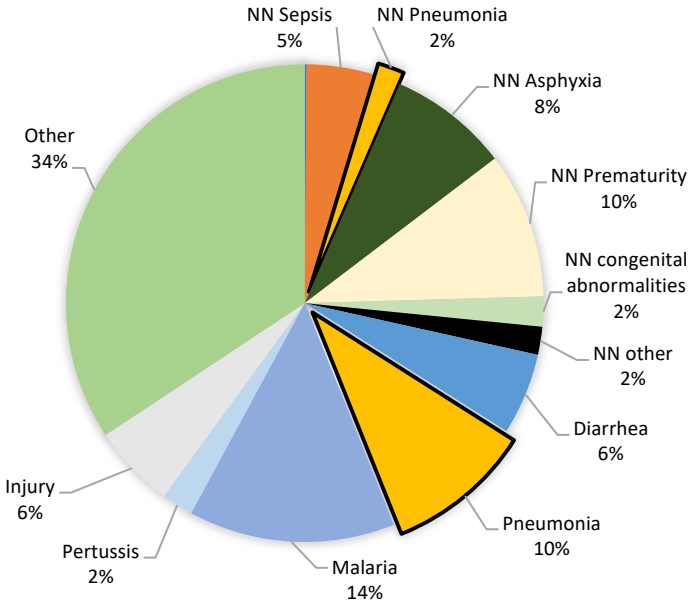


Figure 2: DRC Under 5 Cause of Death (%) 2030, Baseline

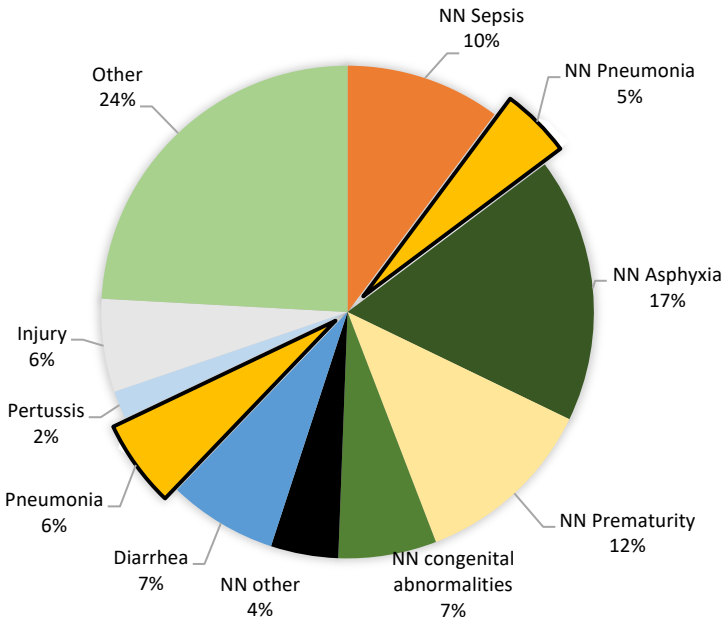


Figure 3: Ethiopia Under 5 Cause of Death (%) 2030, Baseline

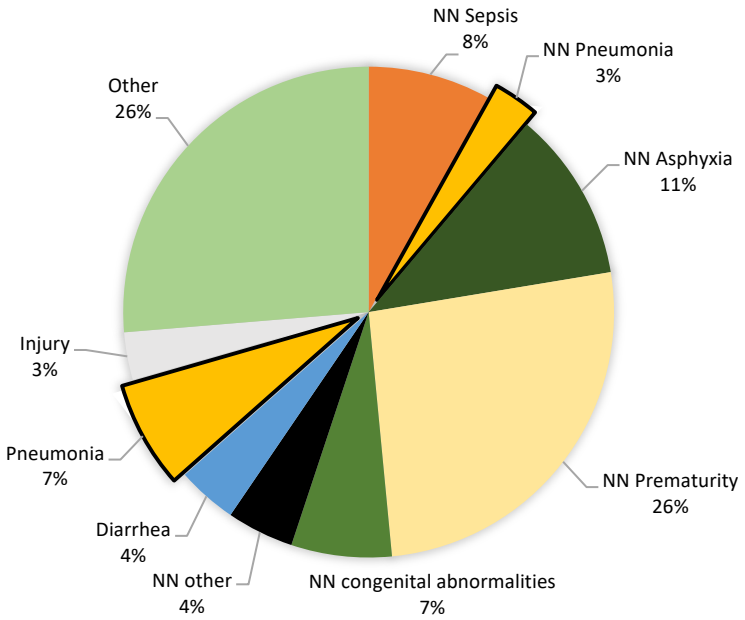


Figure 4: India Under 5 Cause of Death (%) 2030, Baseline

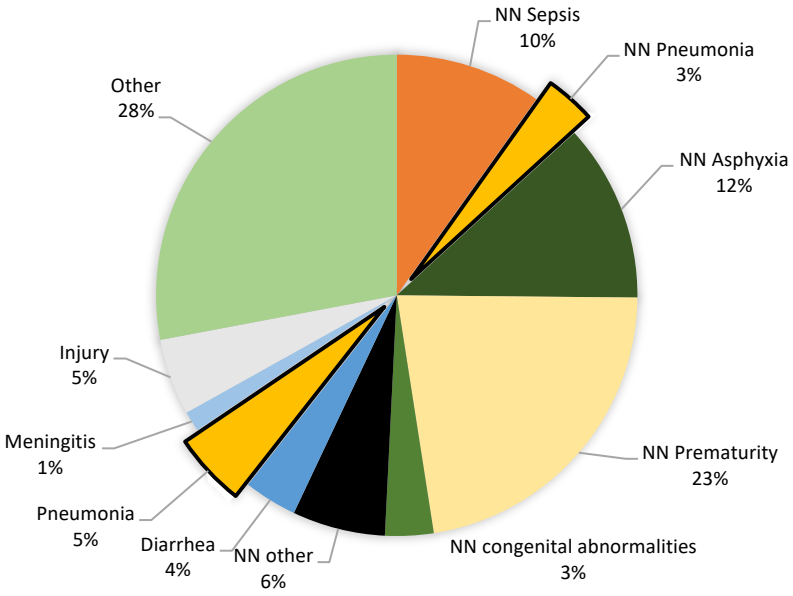


Figure 5: Pakistan Under 5 Cause of Death (%) 2030, Baseline

Appendix 2: Causes of Death Under-five, Goal 2030

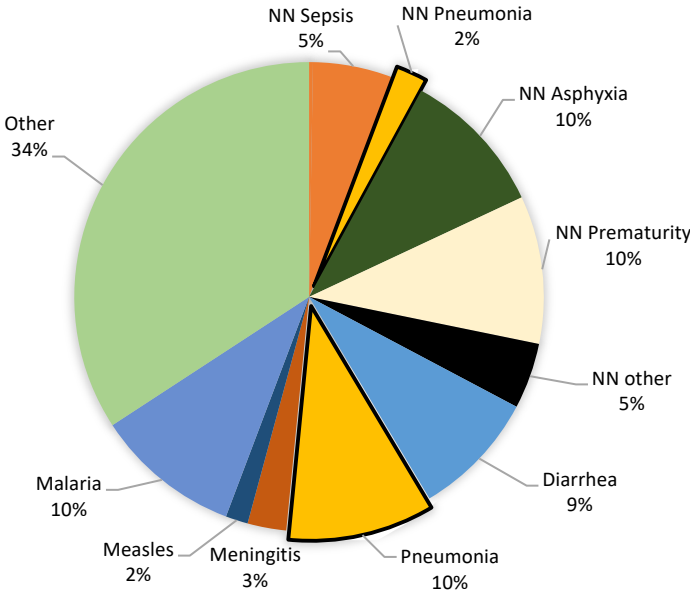
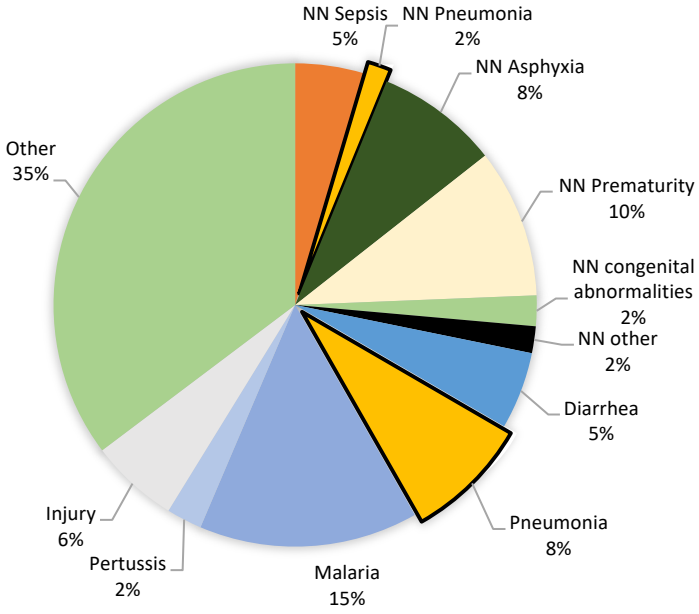


Figure 1: Nigeria Under 5 Cause of Death (%) 2030, Goal



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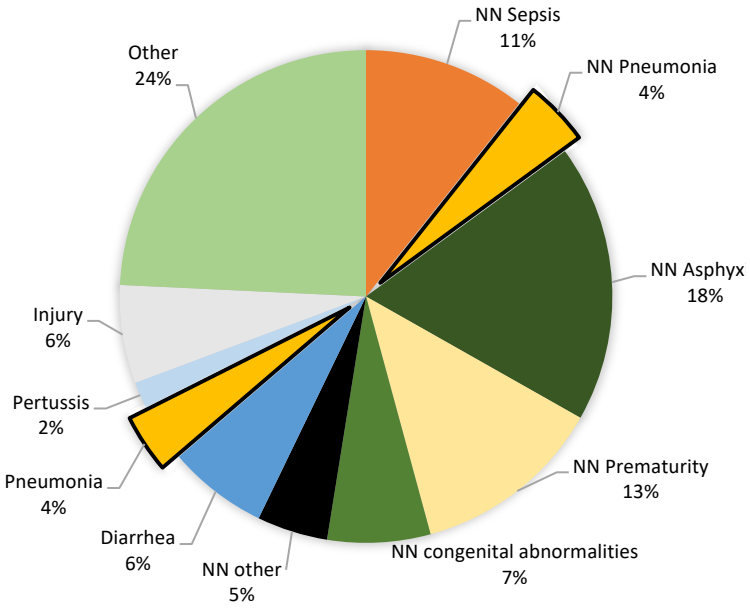

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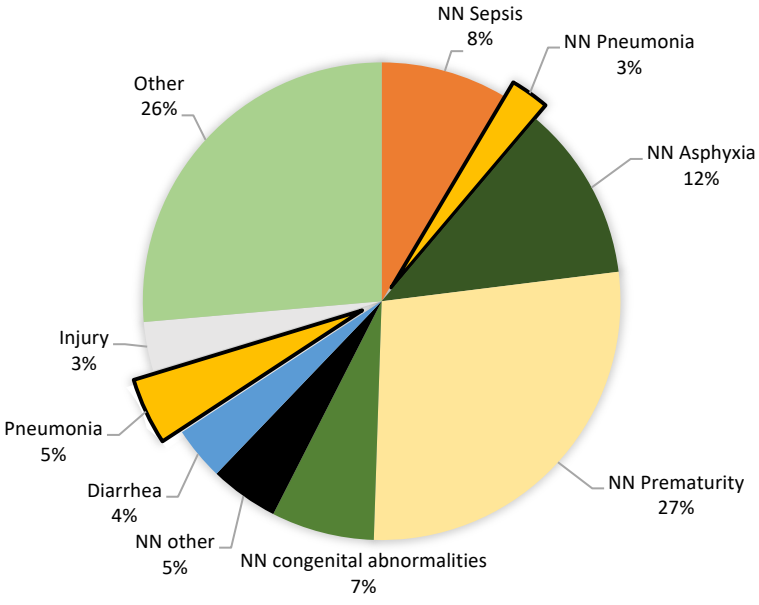

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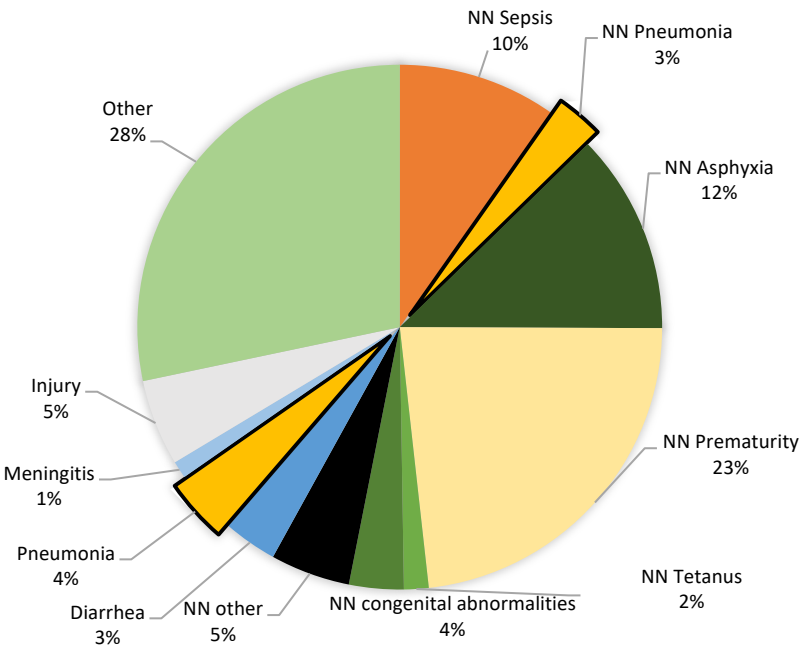


Figure 5: Pakistan Under 5 Cause of Death (%) 2030, Goal

Appendix 3: Additional Child Lives Saved by Cause, Goal 2020-2030

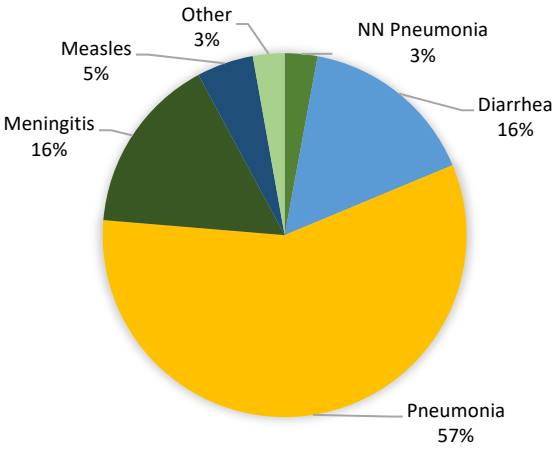
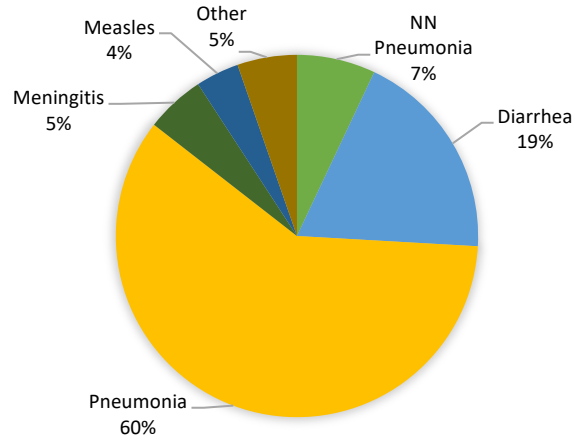


Figure 1: Nigeria Additional Child Lives Saved by Cause (%) 2020-2030, Goal



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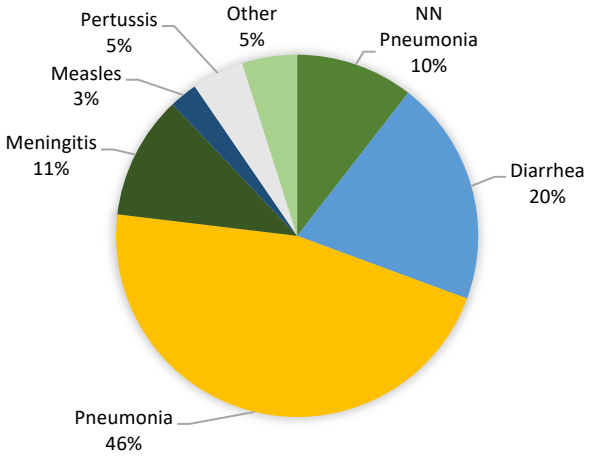

Figure 3: Ethiopia Additional Child Lives Saved by Cause (%) 2020-2030, Goal

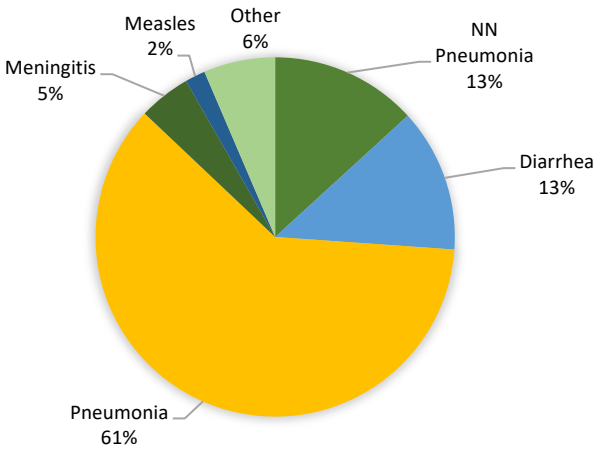

Figure 4: India Additional Child Lives Saved by Cause (%) 2020-2030, Goal

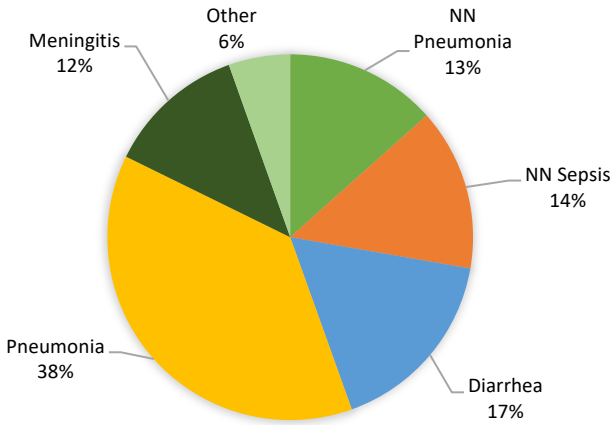

Figure 5: Pakistan Additional Child Lives Saved by Cause (%) 2020-2030, Goal

Appendix 4: Pneumonia Death Rate by Country

Country	Year	Live Births	Pneumonia Deaths	Pneumonia Death Rate (per 1,000)
India	2020	26,932,600	130,378	4
	2030 BL	24,105, 860	123,057	5
	2030 Goal		82,810	3
Pakistan	2020	5,460,955	34,305	6
	2030 BL	5,291,545	32,363	6
	2030 Goal		26,164	4.9
Nigeria	2020	7,443,952	152,522	20
	2030 BL	8,593,352	173,835	20
	2030 Goal		126,009	14
DRC	2020	3,522,894	42,340	12
	2030 BL	4,192,389	49,744	11
	2030 Goal		40,804	9.7
Ethiopia	2020	3,300,515	18,775	6
	2030 BL	3,409,212	19,244	5.6
	2030 Goal		14,431	4.2

Appendix 5: Progress Towards GAPPD Pneumonia Targets