Indoor air pollution as an issue of nonattention in Nairobi's informal settlements

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Abstract

58 percent of Nairobi's population live in slums under extremely poor and unhealthy conditions. In these settlements, pneumonia is one of the top causes of health issues and deaths among children and adults, for which indoor air pollution is a known contributor. Yet, the topic of indoor air pollution receives no attention. Regulatory frameworks and budgets for indoor air pollution do not exist and humanitarian organisations neglect the topic despite its drastic health effects. This paper addresses the dynamics of indoor air pollution from two sides: It investigates the underlying structural mechanisms of organisational and governmental attention dynamics. It also analyses how government policies interact with these mechanisms and create indoor air pollution and health outcomes. We employed participatory system dynamics to investigate attention to indoor air pollution, to develop the model structure, policies and to discuss wider consequences. Participants included community members, local and central policy-makers, parastatals, NGOs and academics. Modelling suggests possible avenues to improve indoor air pollution in Nairobi's informal settlements and the participatory process also gave insights into their feasibility. The participatory work also showed some potential of awakening and mobilising community attention.

Keywords

Attention, indoor air pollution, health, Nairobi, informal settlements

1 Introduction and objectives

Nairobi city, according to the most recent national census was home to 3.14 million inhabitants (Kanya National Bureau of Statistics, 2010), having grown from just under half a million at the country's independence in 1963. The city's population growth is fuelled both by natural increase and migration from rural and other urban areas. For a long time, Nairobi has remained the country's principal city and it remains an attractive destination for people looking for livelihood opportunities that are lacking in the mostly agricultural rural areas.

The rapid growth of the city population has not been accompanied by sufficient provision of affordable housing and other social amenities leading to the mushrooming of slum settlements. It is estimated that Nairobi alone has over 150 slum settlements, scattered across the city. These settlements which occupy less than five percent of the city's land mass are home to an estimated 60–70 percent of the city population (Beguy et al., 2015). Numerous studies have reported the challenges that slum residents face, including the near absence of the public sector and poor access to public goods and services; with negative implications for various health outcomes as well as other outcomes such as educational attainment (African Population Health Research Center, 2002, 2014; Kyobutungi, Ziraba, Ezeh, & Yé, 2008; Mugisha, 2006).

Typical housing units in slums have tin/corrugated iron roofing and mud or tin/corrugated iron sheet walls. Most households rent one room measuring about 10ft by 10ft and these rooms serve as the kitchen, bedroom and living room. The rooms usually have one door and one window although in some cases there are no windows at all. Most households rely on kerosene for cooking and lighting as well as charcoal or wood for cooking. In the poorest of households, the use of plastic waste, cloth rags and other unconventional materials as fuels has been reported (Muindi, Egondi, Kimani-Murage, Rocklov, & Ng, 2014) with grim implications for indoor air pollution and associated toxic fumes. Further, a separate study found that about seven percent of the respondents are exposed to cigarette smoke while in their homes, where one or more members of the household are reported to smoke. The same study recorded high levels of particulate matter with aerodynamic diameter of 2.5 microns and less ($PM_{2.5}$), especially in the evenings and in households burning charcoal/wood and kerosene (Muindi, Kimani-Murage, Egondi, Rocklov, & Ng, 2016). Other than housing features and behaviours that impact on the air quality, slums are located in areas close to primary sources of air pollutants. For example, many slums are built near busy highways, within industrial zones or in close proximity to open dumpsites (though in most cases it is the dumpsite that is sited close to the communities and not vice versa). Indeed, outdoor measurements of $PM_{2.5}$ concentrations in slum areas found that there were spatial and temporal variations with slum villages close to major outdoor sources such as dumpsites having higher concentrations, while mornings and evenings were also noted to have elevated levels (Egondi, Muindi, Kyobutungi, Gatari, & Rocklöv, 2016). In a context of weak or non-existent policies to minimise emissions from various sources, slums experience high exposure to outdoor air pollution compared to non-slum areas of the city.

It is against this backdrop that the project, Housing in Nairobi's Informal Settlements (HINIS), was launched in June 2016. The project is a collaborative effort. HINIS brought together multiple stakeholders including government officials, researchers and academics, NGO representatives as well as community members from two of Nairobi's informal settlements – Korogocho and Viwandani – where APHRC has been working for over a decade. We worked closely with these different stakeholders to understand the primary needs and constraints around housing and health in Nairobi's informal settlements. The overarching goal of HINIS was to maximise the opportunity for transformative change in the urban environment to achieve health and sustainability objectives.

We quickly observed that indoor air quality significantly contributes to the health burden of slum residents. For example pneumonia, for which household air pollution is a known contributor, is the fourth most common cause of death among adults (Egondi, Kyobutungi, Kovats, Muindi, & Ettarh, 2012) and the leading cause among under five year old children, more frequent than diarrhoea, malnutrition or birth-related causes (Ye et al., 2009). At the same time, however, governments and humanitarian organisations focus on issues such as infrastructure, maternal care and malaria, but they pay little attention to pneumonia and indoor air pollution.

This paper therefore investigates the issue of indoor air pollution in two Nairobi slums. It assesses the drivers of poor air quality and develops a system dynamics model showing interactions between drivers of poor air quality and policies aimed at addressing them. It also estimates the potential contribution to health and well-being arising from implementing appropriate policies. At the same time, it reports on a pilot of using participatory system dynamics to understand the challenges of poor air quality, explore policy options and develop potential solutions.

2 Air pollution and healthcare context

The underlying governance and financial structures affect the indoor air pollution within informal settlements. Understanding which stakeholders are the key decision makers who allocate budgets is useful when moving forward with the project and trying to influence change.

The 2015/16 national and county level health budget data suggests that the Ministry of Health and local counties distribute their funds (KES 144bn) to recurrent expenses (KES 90bn), such as personnel, drugs and medical supplies, as well as to development expenditures (KES 54nb), i.e. construction of buildings, federal and local health programmes (ex. free maternity care), as well as initiatives funded by international donors. The Ministry of Health accounts for a yearly KES 19bn of funds arriving from donors, most of which is earmarked to HIV, reproductive health, immunisation and other health system support programmes.

The 2015 total planned health expenditures in Nairobi specifically account for KES 6.5bn. Over 80 percent of this is to pay for recurrent expenses, the remainder is to development, primarily building hospitals and health centres. Programmes focusing on preventive and promotive health services account for a total budget of KES 43 million, divided into five categories: TB, Malaria, Family planning and Environmental Health. There are no specific mentions of any programme focusing on air pollution within the Nairobi country council's health accounts. Looking at it more broadly, pollution control appears under Environment, Water & Energy sector, focusing on environmental monitoring and enforcement, but is not targeted towards air pollution specifically.

Yet slum residents hardly participate in existing schemes such as the National Hospital Insurance Fund (NHIF) that all working Kenyans contribute to. With monthly contributions between KES 150 and KES 1700, KES 500 for the self-employed, the scheme is costly compared to the estimated average monthly income in a Nairobi slum of KES 4000 per person (Desgroppes & Taupin, 2011). It does not match the informal work that slum dwellers often pursue either. Reports suggest that only seven percent of the poorest 40 percent of Kenyans are covered under this scheme (FSD Kenya, 2016), applicable to most slum dwellers studied during this project. Therefore these poorest 40 percent frequently use savings, rely on social networks or sell assets to pay for health-related costs (Gubbins & Ravishankar, 2016; Zollmann & Ravishankar, 2016).

It has been established that large benefits can be gained from reducing air pollution, e.g. through switching to cleaner fuel sources such as LPG (Morgan, 2015). Despite apparent benefits, there are currently no programmes focusing on air pollution from a health point of view, neither at federal nor at county level. This might be due to lack of specific internal or donor funding, but could also be the result of a lack of understanding at governmental level of the importance of the issue.

3 Methodology: participatory system dynamics

To address indoor air pollution, this study combines different methods: participatory system dynamics modelling and engagement in workshops as well as further model refinement and modelling off-site. We also conducted health impact modelling using a life table model, but do not detail it is this paper. The participatory system dynamics approach allowed us to make use of the different kinds of expertise available in our interdisciplinary stakeholder groups and at the same time to inform them and our workshop through state of the art modelling.

SD modelling is used to organise the knowledge in a visual structure that promotes learning and allows policy design through simulation. This was done by asking participants to identify the chains of causality within the system, by asking questions such as: *What are the main sources of indoor air pollution in the slums? What are the main drivers for these sources?* Following this process, the causal structure of the system can be captured within the model and important causal feedback loops can be identified.

As we were addressing a complex issue involving multiple perspectives and groups as well as implementation challenges, we used a participatory approach. Allowing policymakers to rely on their own thinking process to model the situation and subsequently evaluate alternative policies offers several advantages. For instance, using *Participatory System Dynamics* engenders a sense of ownership and commitment to the outcome of the modelling process and in this way increases the chances of successful implementation of resulting policies (Vennix, 1996).

We brought in real world data back in the office in the period of October 2016 to December 2016 to develop a quantified simulation model from the collaborative map generated through stakeholder workshops. To make concrete policy recommendations, we moved as far as possible towards formal stock and flow modelling and simulation. Yet, in several areas of this research, quantifying variables and obtaining data for them has posed some challenges.

The modelling relies on recent monitoring studies that estimated average exposure to particulate matter ($PM_{2.5}$) in Korogocho at 108.9 µg/m^3 in homes (Muindi et al., 2016) and 166.4 µg/m^3 in ambient air (Egondi et al., 2016). Although these studies involved relatively limited sampling, we use those estimates here as the basis for illustrative calculations of the health burden associated with $PM_{2.5}$ in Korogocho. Under the crude assumption that local residents spend 50 percent of their time indoors at home and 50 percent of their time outdoors, the current time-weighted average $PM_{2.5}$ exposure is 137.7 µg/m^3. Our health life table modelling suggests that among the 180,000 people living in Korogocho, particulate matter ($PM_{2.5}$) is responsible for about 250 deaths annually, of which about 75 are children aged under 5. These deaths result in almost 12,500 years of life lost and more than 10 years of lost life expectancy at birth.

4 Our participatory process and its intermediate results

The primary means used to implement the participatory process was facilitated discussions during two rounds of workshops in Nairobi. We held the first round of workshops in September 2016 and the second one in January 2017. We reached out to a diverse group of stakeholders to ensure that different aspects of housing in informal settlements, air pollution and its effects on health would be discussed extensively which would contribute to the development of a system dynamics model. Initial discussions during the first round of workshops involved a broad range of stakeholders that included both experts as well as non-experts (lay-people). Later, the discussions mostly involved individuals with expertise on air quality and its impacts on health, as well as those working on policy development and implementation. These discussions with experts served to refine the input received during the workshops with broader participation.

Besides workshops, we also used follow-up surveys and focus group discussions as part of the participatory processes. Following the first workshop, we used a survey tool to solicit opinions on the relative importance of different policies that aim to address air quality issues. This prioritisation by the stakeholders themselves informed the selection of policies used in the modelling. During the second round of workshops, we held focus group discussions (FGDs) with community members from Korogocho and Viwandani, right within the informal settlements where they live. The discussions tackled indoor air quality and housing. These participants provided rich information on their experiences, their agency and the challenges they face in trying to improve the quality of indoor air within their homes. The FGDs were of mixed gender and age because the discussion did not cover sensitive issues that would require disaggregation by gender or age.

Following each round of workshops, the discussions were transcribed to capture details of the issues raised by the different stakeholders. These transcriptions formed an important part of the qualitative data that was included in the system dynamics model.

4.1 Project participants

The participants of the projects who consented to participate were drawn from the following sectors:

- **Community members** from Korogocho and Viwandani, two informal settlements in Nairobi where APHRC has been working for over a decade. The community members were represented by tenants, landlords and community leaders. These representatives offered their opinions based on their lived experiences while local leadership offered insights into current developments that could have a bearing on housing and consequently indoor air quality. For instance, the ongoing land allocation and issuance of title deeds to Korogocho residents is expected to have a positive impact on quality of housing and consequently on indoor air quality.
- **Academia and researchers** from local institutions including the University of Nairobi and Jomo Kenyatta University of Agriculture and Technology. They possess expertise in air quality monitoring, alternative fuel development as well as design and urban planning. These individuals provided technical input into the discussions.
- **Government departments** working at the national and sub-national levels. The sub-national representatives were drawn from two counties – Nairobi and Kisumu. Participants from Nairobi County represented the health and environment departments as well as the slum upgrading programme. Kisumu County was represented by officials from the health, environmental and economic planning departments. These government departments are the 'owners' of the problem identified in this study given their mandate as implementers of programmes in their respective counties.
- **National parastatals** that work in housing, health and environmental regulation. These were the National Housing Corporation (NHC), National Hospital Insurance Fund (NHIF) and the National Environmental Agency (NEMA). These stakeholders were instrumental in providing insights into policy and practice as well as pathways into operationalising some of the outputs of the two workshops.

- **Non-governmental organisations (NGOs)** and civil society organisations with interests in housing or air quality such as the Stockholm Environmental Institute, Global Alliance for Clean Cookstoves (GACC) and Kenya Alliance of Residents Associations (KARA). They brought into the discussions perspectives from other contexts facing similar challenges.
- **UN agencies** focused on environment, housing and urban planning i.e. UN Environment and UN Habitat. Representatives from these organisations provided technical input into the discussions based on their previous and ongoing projects as well as insights from ongoing global efforts to improve urban housing and air quality.

4.2 Workshop I: Hopes for the future of Nairobi slums

While the HINIS project most closely focuses on air pollution, on Day I we started with a broader scoping/visioning exercise to explore pressing issues for potential future projects. After initial opening introductions and presentations, we ran a participatory activity in which we elicited participants' hopes for the future of informal settlements. We then sorted and clustered these *hopes* on the wall around common themes. Figure 1 identifies the emerging themes.

Figure 1: Hopes

Subsequently, we used a voting system to prioritise the identified clusters or themes, as viewed by participating stakeholders. Table 1 lists the identified clusters of issues in order of importance according to participants:

Table 1: Ranked clusters of hopes

Rank	Cluster of *Hopes* (Issues)	Number of votes
1	Integrated Governance and Management	26
2	Land Tenure and Ownership	25
3	Services Improvement	8
4	Implementation of Integrated Waste Management	5
5	Socio-Economic Empowerment	3
6	Infrastructure Development and Improvement	2

During the afternoon, we selected the three highest ranked themes, together with the fourth theme of indoor air quality as the central topic of the HINIS project, to continue working on and define more closely. According to their interests and expertise, participants formed four workgroups around these four topics according to their interests and expertise and spent several hours discussing each of these topics in more depth at their table. The purpose of the afternoon exercise was to develop *preliminary project proposals* around each of the themes. These *proposals* included elements such as project title, background, problem definition, problem type, primary audience and potential policies. At the end of the group activity, participants reconvened to the plenary to present their work and get feedback on it from other groups. The preliminary project proposals developed on this day has the potential to be used in order to define other small or large projects within the context of Nairobi's informal settlements.

The agenda for Workshop I is presented in Table 2.

Table 2: Workshop I agenda

Time	Activity	Objective
08.30 – 9.00	*Coffee and registration*	
09.00 – 10.00	**Welcome, introductions, opening presentation**	Background
10.00 – 11.00	**Hopes elicitation activity**	Exploring future scenarios for Nairobi informal settlements
11.00 – 11.30	*Coffee break*	
11.30 – 12.00	**Prioritisation of hopes**	Ranking themes/clusters according to perceived importance/urgency
12.00 – 13.00	*Lunch break*	
13.00 – 15.00	**Specifying the most pressing issues**	Developing useful problem definitions and project proposals
15.00 – 15.30	*Coffee break*	
15.30 – 17.00	**Group presentations**	
17.00 – 17.30	Closing	

4.3 Workshop II: A causal map of indoor air pollution

The second workshop day focused on the issue of indoor air quality in Nairobi's informal settlements. We started the day by identifying the most central variables concerning indoor air quality and related policies in addition to the ones identified on the previous day. We paired up participating stakeholders and asked each pair to spend a few minutes to list as many key variables in this context as they can. Facilitators then elicited these variables one by one, in a round-robin fashion and listed on the board. The listing was done under three categories: (a) policy variables, (b) drivers and (c) indicators. Where there was disagreement as to the variable name or under which category a certain variable should be listed, we discussed it until we reached consensus. The list of elicited variables sorted under three categories can be seen in Table 3.

Table 3: List of identified variables

Policy Variables	Drivers	Indicators
• Monitoring of air quality • Emission standards • Standards on fuel quality • Appliance performance standards • Building standards • Promotion of clean fuels • Investment in economic empowerment • Health impact assessment • Industry environmental audit and assessment • Public publication and scrutiny of data • Enforcement • Zoning • Land subdivision	• Prevalence of clean cook-stoves • Prevalence of clean lighting systems • Awareness of health impacts • Awareness of green appliances • Price of clean appliances • Outdoor air pollution • Implementation of emission standards • Implementation of building public health standards • Monitoring capacity • Prevalence of clean cooking fuels • Population density • Intensity of nearby industrial pollution • Poverty (wealth index) • Precarity (precariousness) • Ventilation characteristics • Fuel stacking • Level of education • Literacy rate • Availability of clean cooking stoves • Prevalence of optimal ventilation behaviour • Burning of rubbish • Price of clean fuels • Availability of clean fuels • Hours stayed at home • Perceived security and use • Effect of house type	• Indoor air pollution (PM2.5, CO, black smoke) • Outdoor air pollution • Prevalence of respiratory diseases • Health outcomes o Days missed at work and other secondary indicators • Pollutant-attributable burdens (child respiratory illness, IHD, COPD)

Subsequently, the facilitators briefly introduced the *System Dynamics* methodology, which is the predominant modelling approach in this project. In this project we built a formal System Dynamics model, starting with a participatory causal loop diagramming workshop with stakeholders with various affiliations and with different areas of expertise. Figure 2 depicts (part of) the *causal loop diagram* (CLD) developed by the participants in Workshop II. Facilitators with expertise in System Dynamics modelling guided this process. As can be seen, the level of *indoor air pollution* is at the heart of this diagram, with various driving variables surrounding it. We later transferred this picture into the Vensim System Dynamics simulation software (Figure 3), to be used as basis for a formal quantified model useful for policy simulation.

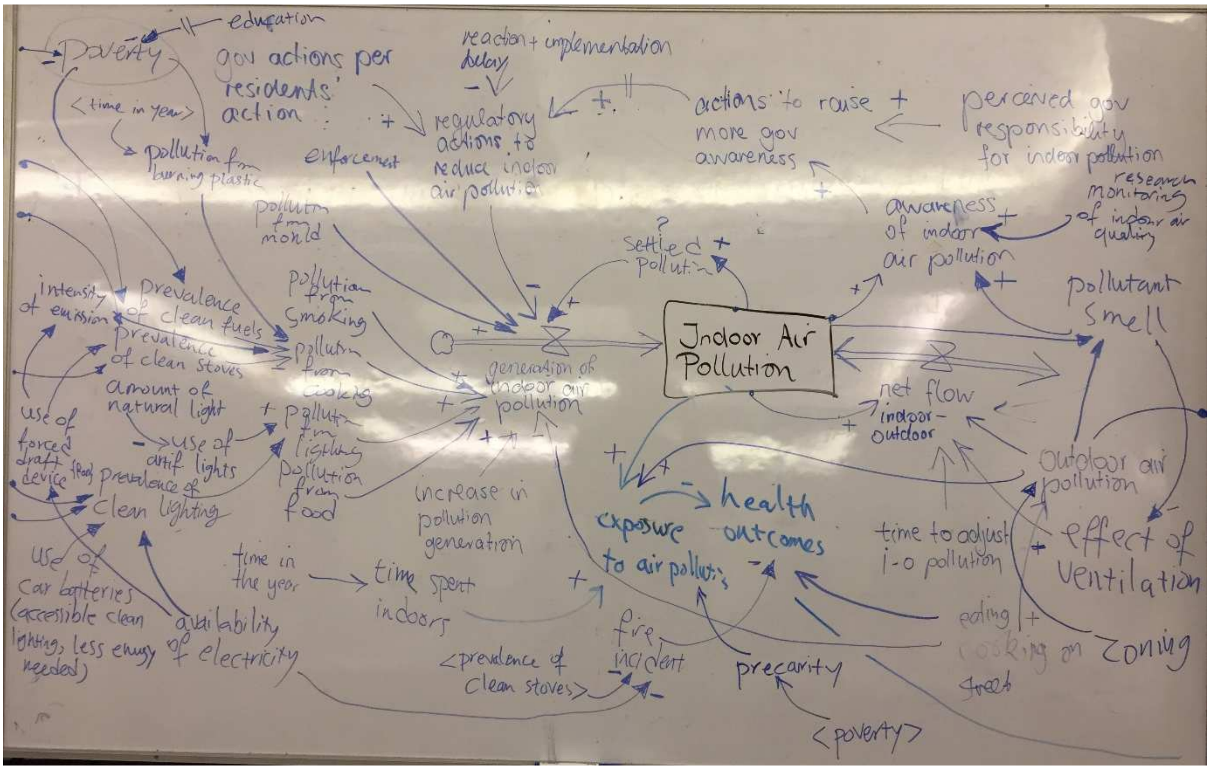


Figure 2: Causal Loop Diagram developed during Workshop II

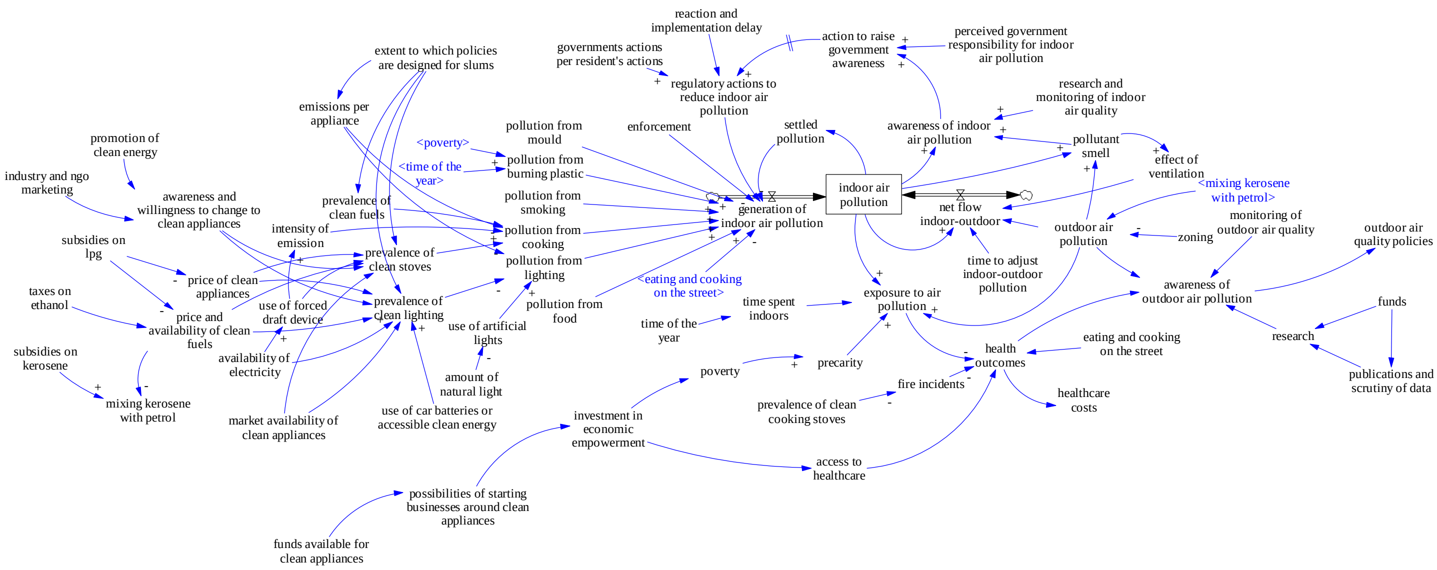


Figure 3: Causal Loop Diagram transferred into Vensim

The resulting qualitative diagram then needed to be refined, quantified and parameterised to obtain a formal model that can be simulated and used for policy analysis. For this purpose and within the context of this pilot project, we needed to focus on a limited number of policies in order to delineate the boundaries of the model and be able to delve deeper into those particular focus areas with a more developed version of the model. Therefore, we circulated a questionnaire to our stakeholders asking them to rank the importance of policies identified in the course of the workshop. Table 4 shows the final ranking of policies based on stakeholder opinions.

Table 4: Indoor air related policies ranked by stakeholders according to importance

No.	Policy	Average Importance
1	Monitoring of air quality	4.50
2	Fuel quality standards	4.33
3	Enforcement of regulations	4.17
4	Health impact assessment	4.14
5	Emission standards	4.00
6	Promotion of clean fuels	4.00
7	Appliance performance standards	4.00
8	Subsidising or provision of clean appliances	3.83
9	Building standards	3.83
10	Investment in economic empowerment	3.67
11	Industrial environmental audit and assessment	3.60
12	Public publication and scrutiny of data	3.33
13	Zoning regulations	3.00
14	Land subdivision	2.17

On the basis of this ranking, the project team chose the following final list of policies to be included in the formal model:

- 1. monitoring of air quality
- 3. enforcement and good governance
- 4. health impact assessment
- 6. price of kerosene vs. price of LPG
- 6. price and coverage of electricity
- 8. prices of clean appliances
- ventilation and outdoor air pollution

With a clearer focus for the project and better defined boundaries for the model, the project team then refined, quantified and parameterised the above qualitative model into one that can be simulated and used for evaluating the potential short and long-term effects of the above policies. In the following section, we will look at a simplified schematic of this model.

The agenda for Workshop II can be seen in Table 5.

Table 5: Workshop II agenda

Time	Activity	Objective
8.30 – 9.30	*Coffee and registration*	
9.30 – 10.00	**Intro and recap**	Background, orientation, goal clarification
10.00 – 11.00	**Variable elicitation**	Preparation for model structure elicitation
11.00 – 11.30	*Coffee break*	
11.30 – 12.00	**Concept model presentation**	Familiarisation with modelling
12.00 – 13.00	**Model structure elicitation**	Coming up with a causal model of the problems and potential improvements
13.00 – 14.00	*Lunch break*	
14.00 – 15.30	**Model structure elicitation**	Divided into sub-topics: impacts on air quality, health effects and policies
15.30 – 16.00	**Model review**	Identifying the most important insights
16.00	Closing	

4.4 Workshop III: Health impacts and policy effects

The third workshop held in January 2017 aimed at discussing and refining with the stakeholders the model that emerged from the September workshop and discussing the feasibility of policies.

We reviewed the work done on the model to-date showing its evolution from the initial causal loop diagram developed (Figure 2) to that shown in Figure 4. This involved a systematic walk-through of the different elements forming the model and their interactions. We sought to verify with the participants whether these elements and the interactions depicted resonated with them and reflected their understanding of the many inter-linked issues around indoor air pollution in Nairobi's slums. Subsequently, we simulated different scenarios based on the policies selected in the survey conducted following the first workshop. Participants discussed the outcomes of different scenarios modelled, providing perspectives on what resonated with them and what surprised them. The scenarios are discussed in more detail in section 6.2.1 of this paper.

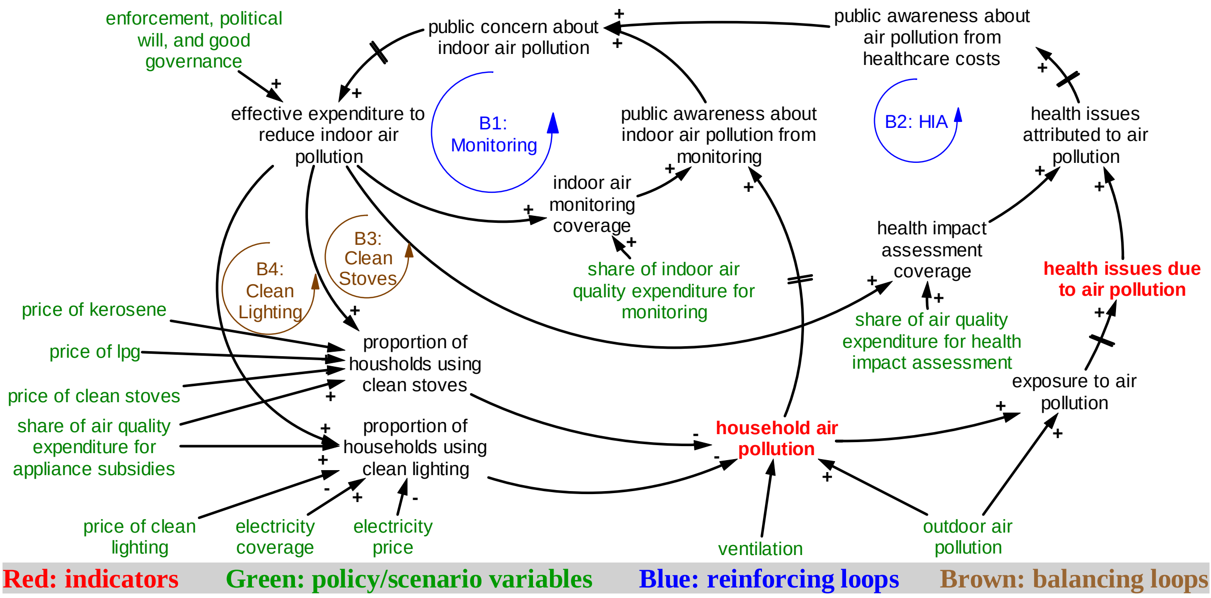


Figure 4: Simplified causal loop diagram discussed during Workshop III, i.e. day one of the January workshop

The principal participatory activity for the day involved prioritisation of the policies selected in the survey. This was done by forming five groups, each of which represented the different classes of stakeholders present. We placed stakeholders in these groups so that they could articulate a unified view based on their similar backgrounds. The five groups formed were:

- County officials
- National parastatals
- Academics and researchers
- UN agencies, NGOs and civil society
- Community members

We asked stakeholders in each group to rank the most important policies that would be critical to ensure achievement of improved air quality in Nairobi's informal settlements. Each group then presented the results of their discussions and the rationale behind their ranking. Stakeholder groups then proceeded to define their role and interests in the improvement of indoor air quality in Nairobi's slums. They further discussed implementation of the selected policies, in terms of who should be the primary actor as well as obstacles and unintended consequences arising from their implementation. While there was no clear consensus on the priority policies, there were rich discussions across the different groups, especially as they elaborated on their own roles and perceptions of other stakeholder roles. Results from the discussions in the plenary are shown in Table 6.

Table 6: Results from the plenary discussions on policy implementation

	Who bears costs?	Who benefits?	Implementation	Barriers / supporting factors
1./3. Monitoring of air quality and health impact assessment	• Public health departments • Academia and universities • Private sector	• All citizens • Public health service (reduced costs) • Insurance companies • Government (better data available → better decisions)	• Barely • UNEP did studies → No policies for air pollution, only regulations! → Hard to enforce • In absence of government action, academia is filling the gap, but typically only for short-term studies	• Lack of overarching air quality strategy and budget at government level • Always beeping device → what exactly is the problem? • People may tamper with monitoring systems • Education can generate demand for this
	Unintended consequences • People might feel 'Oh, we've solved this problem' → reduce investment • It may demoralise people if levels are always high • Unfair use of information, e.g. by insurance companies • Potentially higher costs of health insurance for polluted areas			
4. Enforcement	• Producers	• Citizens	• Barely	• Costs of enforcement (checking, penalizing, etc.) • Combine education and enforcement. Sensitising the public may be a way around enforcement • Encourage entrepreneurship • Turning regulatory body to cash cow (corruption) • Long prosecution times • Low fines and punitive measures • High incentive to not conform
	Unintended consequences • Too much enforcement → cause corruption?			
6. Lower prices of clean fuels, raise price of kerosene	• Central government • Business users • Taxpayer • Matatu drivers	• New consumers • Residents • Businesses • Distributors	• Existing	• Distribution system • Human waste gas systems • Clubs can reduce costs • Community investments
	Unintended consequences • Does not work for poor because of cash flow – poor now pay more for kerosene • More LPG canisters results in more explosions • LPG dist. very profitable → fire incidents more common			

	Who bears costs?	Who benefits?	Implementation	Barriers / supporting factors
8. Provide clean stove subsidies	• Central government	• Households • Entrepreneurs • Corporations • Businesses selling subsidized appliances and alternative fuels	• No	• Initial investment ($40) • Failure to sensitise communities on proper use • Costs for establishing regulatory system. Regulation required!!! • Availability of clean fuels (infrastructure). • Enforcement • Inconsistency of policy • Government internal communications • Must be made profitable for businesses
	Unintended consequences • Some poor quality 'efficient' stoves are even more polluting (CO) • Some commercial organisations pocket carbon credits instead of passing them on to end users • May lead to disemployment in manufacturing organisations if they are unable to manage market competition			

The agenda for Workshop III, i.e. the first day of the January workshop can be seen in Table 7.

Table 7: Workshop III agenda

Time	Activity	Objective
08.30	*Coffee*	
09.00	**Welcome and presentation of participants**	Participants have spoken, feel welcomed
09.10	**Recap and CUSSH**	Background, orientation, trust-building and goal clarification
09.20	**Health impacts**	Presentation and discussion
09.50	**Presentation of simulation model**	Familiarisation of participants with the system dynamics model
10.25	*Break*	
10.45	**Model familiarisation in plenary**	Simulating a number of preconceived scenarios and looking at results Reviewing generated insights in one slide
11.45	**Discussion on model and results**	Discussing simulations, whether the results seem realistic, and what modifications do people suggest to the model
12.15	*Lunch break*	
13.15	**Plenary debate**	Prioritisation of policies, elicitation of obstacles and unintended consequences
15.30	**Summary of insights**	Relation of this work to general concerns
16.00	Closing	Ideas about project future, hopefully feeling of time well-spent

4.5 Focus groups: Real impediments

On the day following Workshop III, the facilitation team met with the two slum communities where the APHRC runs the demographic surveillance. This allowed us to follow up on some emerging issues from the workshops. The meetings were convened with the respective leaders of the two slums (the chiefs who represent the national government at the administrative location in which the two study sites fall). Figure 5 shows one of these sites.

Figure 5: View of Korogocho

After meeting with the chiefs individually in the morning, we facilitated two focus group discussions with residents of the two communities. The groups consisted of about 15 participants each in Korogocho and in Vivandani. We discussed further on indoor air, the barriers residents see in their adoption of clean cook stoves and other issues touching on housing, outdoor air and community/individual agency to agitate for action against known polluters. In Vivandani, only one participant owned a clean cook stove.

'*So we end up using kerosene or even charcoal*.' '*There are some of us who cannot afford that gas or electricity and use the stove therefore it depends on the income*.'

We learned that a $35 investment for a clean cook stove is too high for the households and that the initial costs of canisters are too high as well, but we discussed the opportunity of forming self-help groups to afford the initial investments.

Participants alluded to outside air pollution as well.

'*Like around 6 a.m. when you wake up at 5 a.m. you feel like it is difficult to breathe, because the air is very bad even outside. Because that is the time the factories open, the water is now let to the river, all the waste now flows because of those people who* […].'

They attributed some the root causes of this problem to the dumpsites that persist due to corruption.

'*I was saying you can't open the window and these outdoor pollutions they are contributed by the government mostly because we have NEMA, isn't it supposed to deal with those environmental pollutions? But even like this dumpsite already they were told to stop dumping but corruption makes it continue. Because the person will pay money and continue dumping. Like these industries, the government cannot ban them because they benefit. So we'll just continue to suffer because we must open them* [the windows].'

'*When NEEMA comes and gets the self-help group what do you do? You bribe them and the day continues.*'

Participants mentioned that job opportunities and slum upgrading are their most pressing needs. Yet, they were aware of air pollution and that it has health consequences and stressed that further education on air pollution is strongly required. Yet, especially the residents of Korogocho expressed that no organisation has ever educated them on the issue of air pollution. But they emphasised their lack of influence for triggering any change.

These discussions were recorded for later transcription. Table 8 shows the adapted agenda that we followed on the day.

Table 8: Focus groups agenda

Time	Activity	Lead
08.30 – 10.00	*Travel to field sites –Viwandani and Korogocho*	APHRC
10.00 – 11.00	**Courtesy call on Chiefs**	APHRC
11.00 – 13.00	**Focus Group Discussions** • Short oral introduction (What we want to achieve in the project and today and why is it important) • What affects your decisions to buy, to use clean stoves? • Is it relative price of LPG to kerosene that affects the decisions? • What are your perceptions of outdoor air? Have there been any changes in time? • In what area and to what extent do NGOs not follow through and to what extent don't we know it? • What needs to be done to really transform your life positively? • What do you suggest to deal with the problem?	APHRC/ UCL
13.00 – 14.00	**Household visits**	APHRC
14.00	*Close and departure from field*	APHRC

5 A formal model of indoor air pollution in Nairobi slums

Given the potentially high benefits of a reduction of air pollution, we will now investigate the causal structure of the simulation model we created in order to examine how different policies affect indoor air pollution and resident health.

5.1 Model structure

The process resulted in a ~180 variable model that can be accessed in the supplementary files. Due to its complexity, we only describe a simplified causal loop diagram and the main feedback loops in the subsequent sections.

5.1.1 Simplified causal loop diagram

Figure 6 portrays the simplified causal loop diagram arrived at through distilling the key causal skeleton of the formal System Dynamics model. The legend on the bottom explains the colour coding. Starting with the central variable of *household air pollution* highlighted in red as our main indicator, let us move backwards (against the direction of the arrows) along the chains of causality to investigate the key dynamics of the system as modelled here. The key drivers of the average level of *household air pollution* in Nairobi's slums are the levels of *outdoor air* *pollution* and *ventilation* externally and the *proportion of households using clean stoves/lighting* internally. Within this project we were mainly keen on exploring the internal factors, i.e. the prevalence of clean appliances. These prevalence levels are mainly driven by the levels of expenditure for each type of appliance, their prices and also clean fuel prices relative to the price of brown fuel (in this case kerosene). The lower the prices of clean appliances and/or clean fuels, the higher the take-up and usage of these by residents of the informal settlements. In the case of clean lighting, this prevalence is also affected by electricity grid coverage.

The expenditure for subsidising clean appliances comes from the total funds spent for combatting indoor air pollution, *effective expenditure to reduce indoor air pollution.* This expenditure is determined not only by *public concern about indoor air pollution*, but also by the extent of *enforcement, political will and good governance*, defined as an index moving within a range of zero to one and set by the user as a scenario variable. Note the perpendicular *delay sign* on the arrow linking *public concern about indoor air pollution to effective expenditure* to *reduce indoor air pollution* that represents the time it takes from becoming increasingly concerned about indoor air pollution to taking effective action against it. As can be seen on various causal links in the diagram, these delays are accounted for in the formulation of the System Dynamics model and have notable implications on the behaviour of the model, as they do in the real world. *Public concern about indoor air pollution* comes from two sources: either direct monitoring of indoor air pollution levels or through awareness about healthcare costs associated with indoor air pollution, which can be estimated on the basis of information generated through health impact assessment (HIA) studies. The extent to which either monitoring or HIA are systematically carried out in the informal settlements depends on the levels of funds available for each, which are in turn determined by multiplying the total *effective expenditure to reduce indoor air pollution* by the share of this expenditure going to either of these initiatives. The levels of awareness and concern generated through each channel are also driven by the actual levels of indoor air pollution; directly so in the case of monitoring and in the case of health impact assessment, travelling through *exposure to air pollution, health issues due to air pollution* and *health issues* <u>*attributed*</u> *to air pollution*. Exposure itself is a consequence of either *indoor* or *outdoor air pollution*. *Outdoor air pollution* lies outside the scope of this project and it is fed as exogenous data to the model. Its past levels are set according to the limited available real-world data and its future levels is decided upon by the user as a scenario variable.

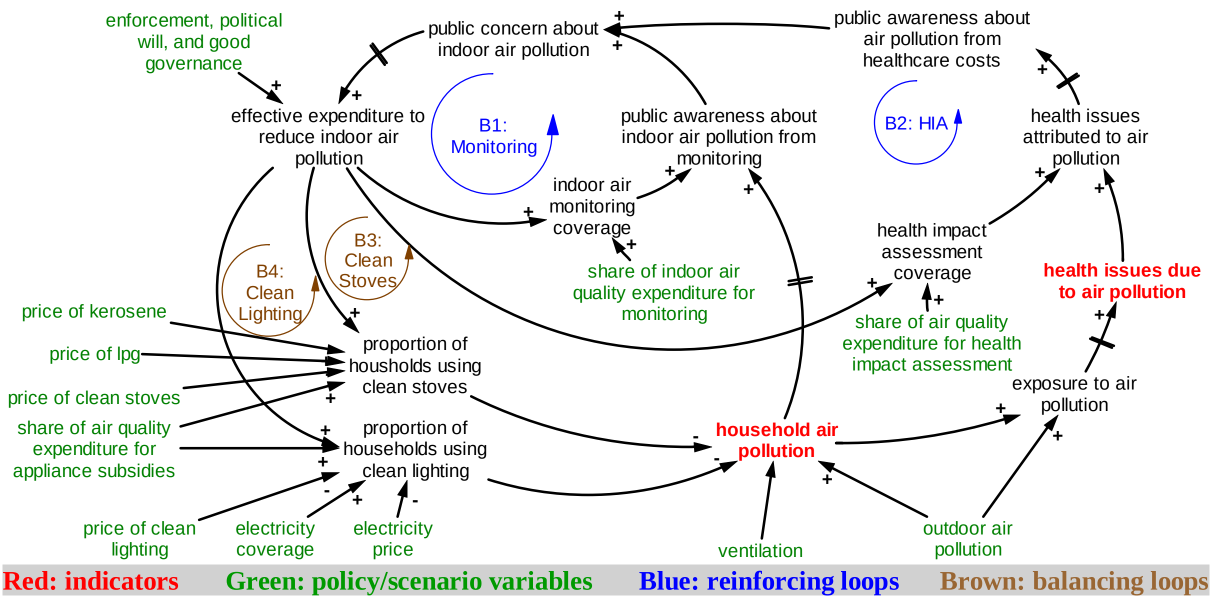


Figure 6: Simplified causal loop diagram of the model

5.1.2 Main feedback loops

It becomes immediately evident while looking at the causal structure in Figure 6 that a number of feedback loops exist within the system that might drive change or counter it in the real world. Four noteworthy feedback loops are identified and numbered in the diagram. *R1: Monitoring* and *R2: HIA* belong to the class of feedback loops known as 'reinforcing', while *B1: Clean Stoves* and *B2: Clean Lighting* are known as 'balancing' loops. This inherently different nature of these feedback loops can be decisive while investigating various policies. It is therefore worthwhile to look at this distinction more closely.

Let us start with the two balancing feedback loops. A potential increase in expenditure for clean appliance would, ceteris paribus, help bring down *household air pollution*, thus making the public slightly less concerned about this issue. A less worrisome public (be it the government, the communities, or NGOs) would then perhaps think that the issue has to some extent been contained and perhaps no longer warrants the previously increased level of allocated funds and decide to divest those additional funds to other more pressing problems, bringing the level of expenditure back close to its initial level; hence the use of the label 'balancing'.

Yet, if the expenditure for monitoring or health impact assessment studies is boosted, once the results of such studies are published, this new information could make the public more anxious about indoor air pollution, leading to a potentially higher budget allocated to this issue for the next year. Therefore, an increase in the *share of indoor air quality for monitoring/health impact assessment* has the potential to enlarge the size of the pie of available resources the next time round. This means that while an increase in fund available for monitoring or HIA studies may initially happen at the expense of fewer clean appliances provisioned for the population, with the passage of time the result of these studies could be a powerful case for demanding a potentially much higher total budget for fighting indoor air pollution, making it possible to spend more not only on similar studies but also, importantly, on a more expansive provision of clean appliances than would otherwise have been feasible. This argument makes a theoretical case for allotting a share of whatever available budget to monitoring and health impact assessment, a policy that we are going to test in the *Modelling results* section 6 on page 18.

5.2 Model validation

The System Dynamics model has undergone extensive validation, both structurally and behaviourally. The structure has been validated against expert opinion in the course of the multi-stakeholder workshops as well as ongoing collaboration with local experts at APHRC. The model has been parametrised using the limited numerical data available from various sources, in particular the NUHDSS database.

The behaviour of the model has also been validated against time-series data from this database. For instance, looking at Figure 7 and Figure 8, it can be seen that the model's *Base Run* (blue curve) captures the general long-term trend in historical data fairly well. Since the focus of this project is long term policymaking, the fact that short-term oscillations are not captured is not considered a handicap of the model for our purpose.

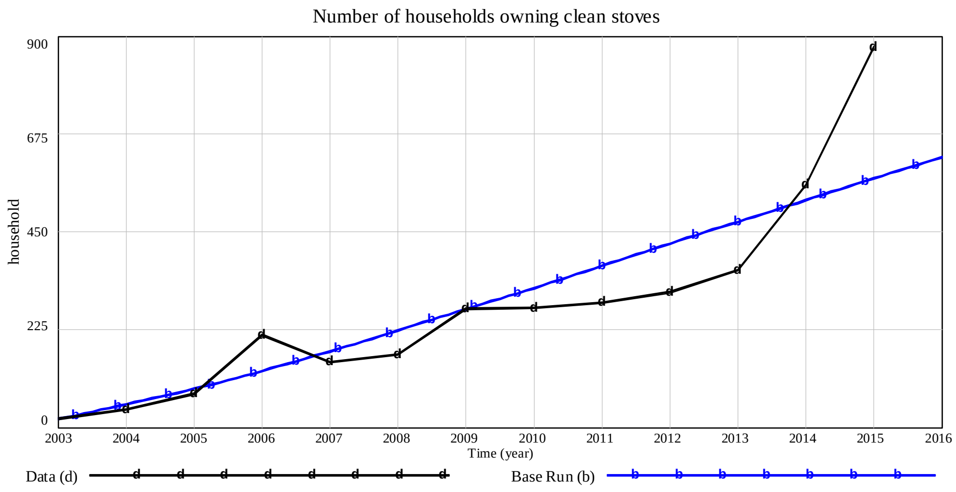


Figure 7: Number of households owning clean stoves. Black curve (d): historical data. Blue curve (b): model simulation.

The scarcity of available time-series data for important variables in the model, including our very central indicator *household air pollution*, posed a challenge to the behavioural validation of the model. This is a limitation that entails a degree of caution regarding the use of the model as the only input to policymaking. Nevertheless, whilst taking such limitations into account, the model still offers valuable insights for policy, as we will further observe in the next sections.

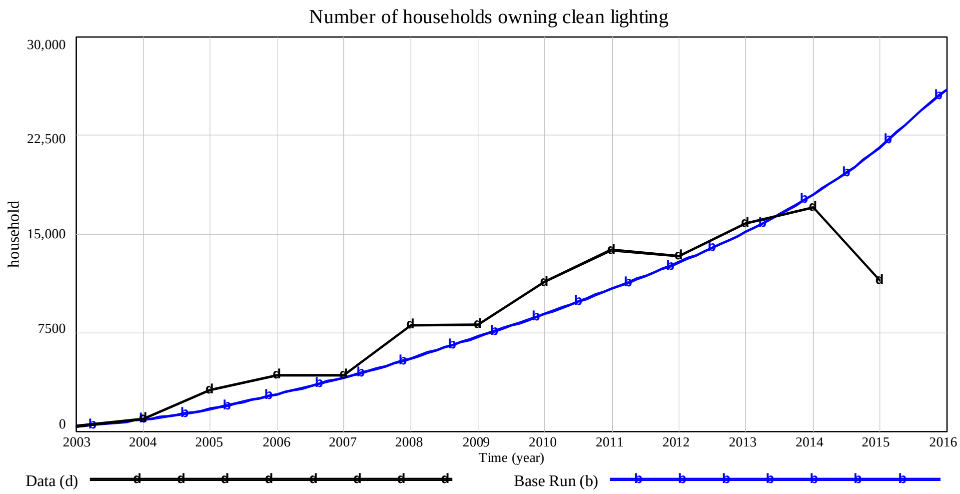


Figure 8: Number of households owning clean lighting. Black curve: historical data. Blue curve: model simulation.

6 Modelling results

In this section, we will start by examining the *Base Run*, which is the model's projection of current trends under business-as-usual. However, as we will see, these projections are not merely extrapolations of current trends. Instead, variables can undergo changes in behaviour mode, as the behaviour of the model is driven by its structure, and not by inputs from outside. This will be made clearer once we look at the *Base Run* for our key variable of *household air pollution.* Afterwards, we will explore four different scenarios and look into potential implications and relative merits of various combinations of policies for improving indoor air quality.

6.1 Base run

Firstly, let us take a look at future developments of our main indicators, under a 'business-as-usual' scenario, according the model projection. Allowing the model to run up to 2030, we will see that *household air pollution* continues to fall slowly, before reaching a plateau before 2020 (Figure 9). As mentioned earlier, we have but one data point relating to past values of average *household air pollution* and therefore we cannot be positive about the actual historical trend in this key indicator. Mean indoor pollution levels were at 108.9 µg/m^3 in homes in 2014 (Muindi et al., 2016). We do, however, have quite good data series of the prevalence of clean appliances and its growth path since 2003, which enables us to postulate the implied behaviour of *household air pollution.* Pollution levels have been falling in the past due to the take-up of clean appliances, particularly the relative precipitous take-up of electric lighting (Figure 10). However, we will soon reach a point where almost all households in the informal settlements under study have access to electricity and electric clean lighting. Therefore, from that point onwards the only way to achieve further improvements in air quality (as captured in our model) is through more extensive take-up of clean stoves. However, as depicted in Figure 10, growth in the prevalence of clean stoves is completely dwarfed by that of clean lighting. In other words, the former is so sluggish that the resulting improvements from clean stoves are almost imperceptible once the prevalence of clean lighting reaches saturation around 2018.

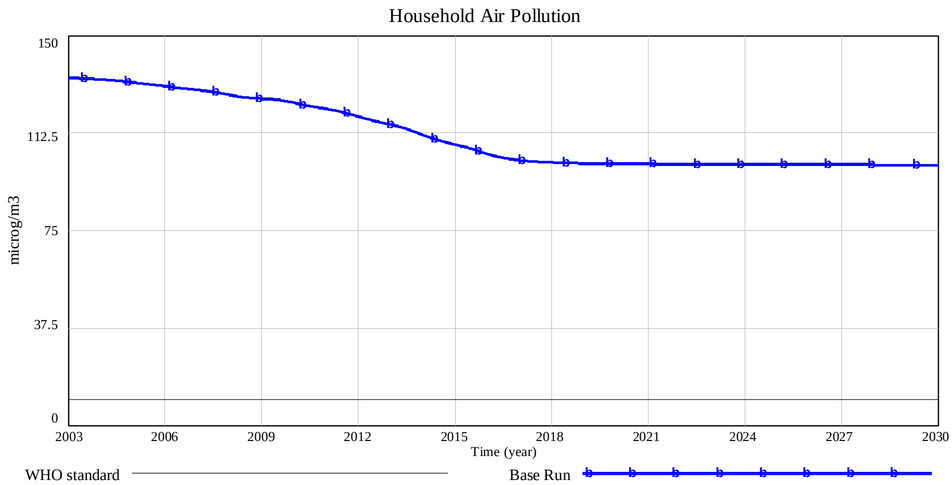


Figure 9: Household air pollution: Base Run (thick blue) vs. WHO standard (thin black)

Insights from modelling

Under business-as-usual, we will soon reach a point where improvements in indoor air quality will come to a halt.

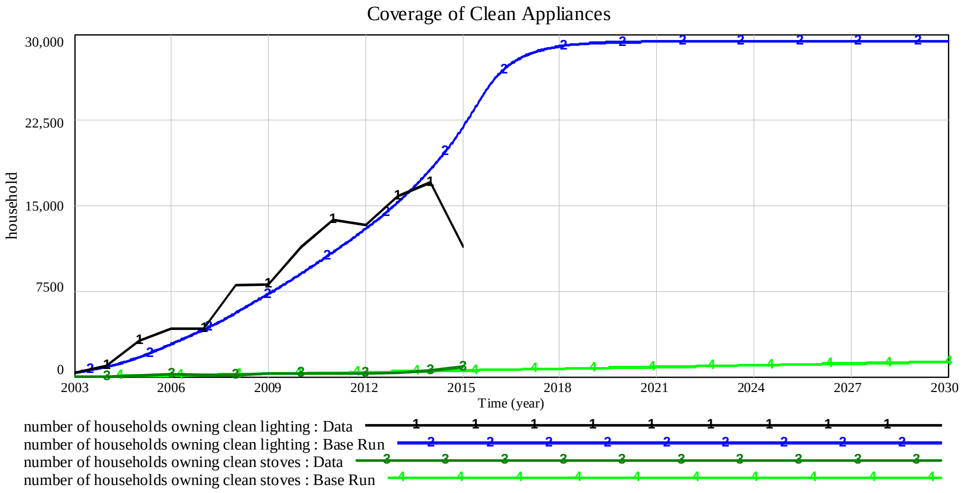


Figure 10: Coverage of clean lighting (Black [1]: Data, Blue [2]: Base Run) and clean stoves (Dark green [3]: Data, Light green [4]: Base Run)

6.2 Scenario analyses

6.2.1 Description of scenarios

In this section, we will examine potential outcomes of four sets of policies. These four scenarios are summarised in Table 9. A detailed characterisation of these scenarios with regards to parameter values in the model can be found in the appendix.

In short, *Scenario I* involves a redirection of subsidies from kerosene to LPG and to supporting local manufacturers of clean stoves. In the model, these assumption are proxied by a step-wise 50 percent increase in kerosene prices by 2023 and a step-wise 25 percent decrease in prices of LPG and clean stoves by the same year. In the more integrated *Scenario II*, we complement the above policies by gradually redirecting the funds previously spent for the provision and subsidising of clean lighting to clean stoves, as the prevalence of clean lighting will soon reach full coverage regardless. In addition, in *Scenario II* we also aim to double *enforcement, political will and good governance* with regards to the regulations and policymaking related to indoor air pollution by 2030. This can be achieved, for instance, via more actively fighting corruption. There are no investments in monitoring or health impact assessment in this scenario.

Table 9: Summarised description of scenarios

Scenario	Summarised description	Notes
Scenario I: fuel and stove prices	• Lower LPG prices • Lower prices of clean stoves • Higher kerosene prices	Adjusting prices of fuels can be attained by lowering/increasing subsidies. Lower stove prices could be a result of supporting local manufacturers. Funds for increasing LPG subsidies or supporting stove manufacturers can be sourced from savings on kerosene subsidies.
Scenario II: + stove subsidies and enforcement	• All of the above in addition to: • Higher share of appliance subsidies spent for stoves, rather than lighting • Higher enforcement, political will and good governance • No investment in monitoring or health impact assessment	In the *Base Run*, a tiny share of available budget (only 2%) goes towards monitoring. In this scenario, it is assumed that even that level of funding is stopped.

Scenario	Summarised description	Notes
Scenario III: + monitoring and HIA	• All of the above in addition to a higher share of available budget spent for monitoring and health impact assessment.	
Scenario IV: + outdoor and ventilation	• All of the above in addition to a drastic fall in outdoor air pollution, along with a drastic rise in ventilation	This is the most comprehensive scenario.

In *Scenario III*, we accompany all the above changes in policy with gradually ratcheting up the share of the available budget going towards monitoring and health impact assessment, up to 15 percent for each by 2023. This will gradually bring down the share of the available budget going to the provision and/or subsidising of clean appliances to 70 percent by 2023. It is worth noting the size of the available 'pie' is not fixed and is endogenously determined under the influence of *public concern about indoor air pollution*. The more concerned the public is, the higher the budget available for fighting it. The *effective* amount of fund is also mediated by *enforcement, political will and good governance*.

Finally, in the most comprehensive *Scenario IV*, we complement the above indoor-air related policies with a drastic (50 percent) reduction in outdoor air pollution, and a drastic (50 percent) increase in ventilation, in order to demonstrate the potential of improving household air via improvements in outdoor air.

6.2.2 Results of Scenarios

We now compare these scenarios against each other and against the *Base Run*. In Figure 11, the project future path of *household air pollution* under various assumptions is shown. Blue is *Base Run*, red is *Scenario I*, dark green is *Scenario II*, light green is *Scenario III* and brown is *Scenario IV*. The graph shows how each scenario performs slightly better than the previous one, thanks to a more comprehensive package of policies implemented, but that the largest leverage comes from a combination of policies with a reduction of outdoor air pollution.

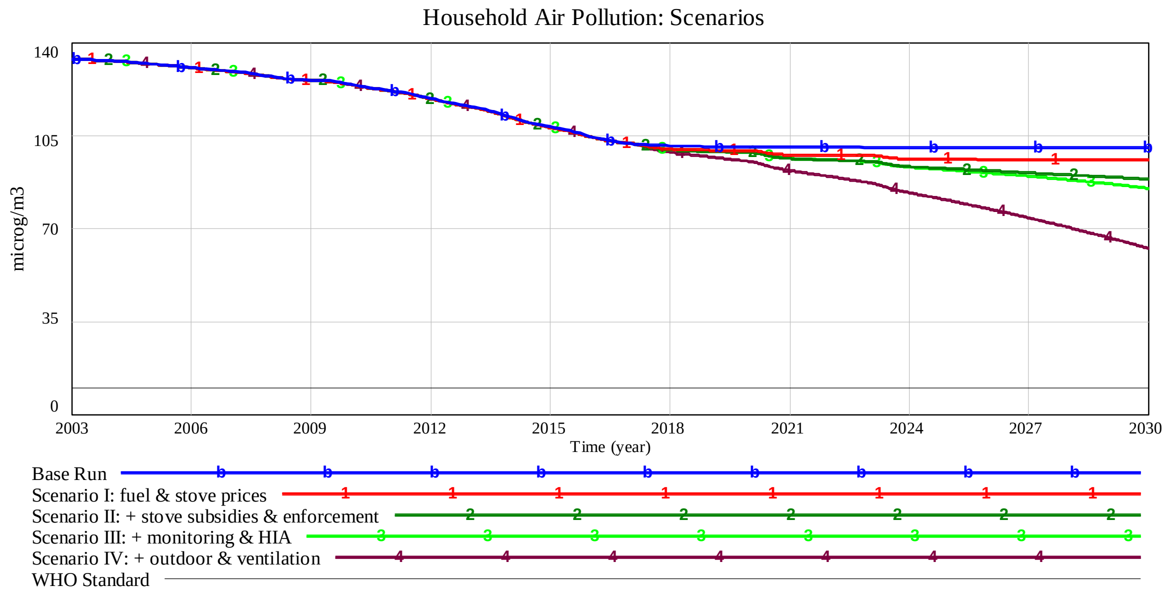
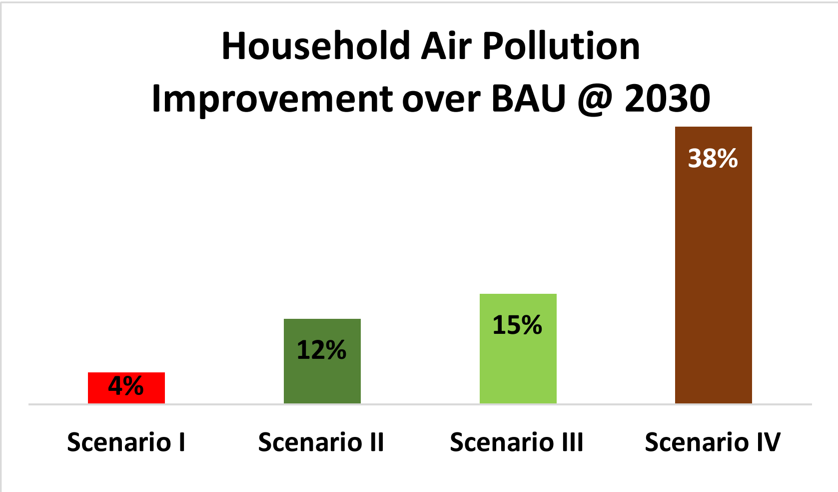


Figure 11: Comparing household air pollution under different scenarios

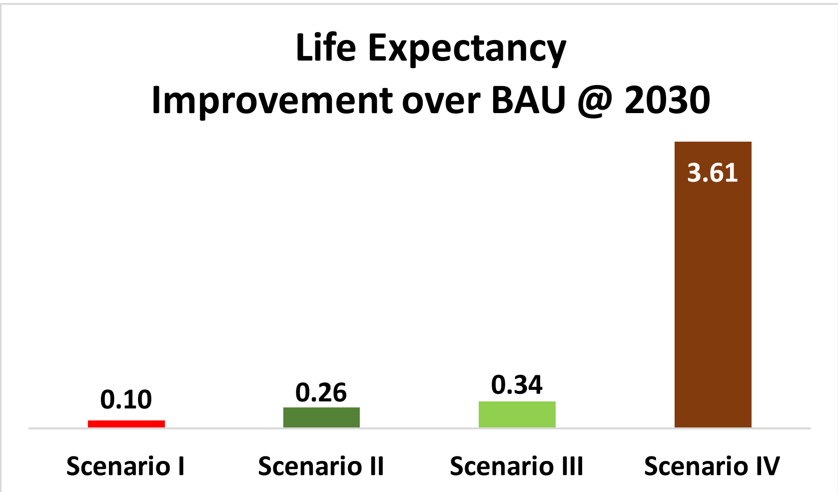
Figure 12 gives a clearer picture of how the four scenarios fare against each other. This bar graph captures the improvement that each portfolio of policies generates over and above business-as-usual (*Base Run*), by 2030. This improvement in *household air pollution* results in a comparable improvement in average life expectancy, as seen in Figure 13.

Results show that manipulating fuel subsidies and appliance prices alone (*Scenario I*) is hardly enough to give inspiring improvements by the end of our simulation period. If, however, we complement this by redirecting more funds towards clean stoves and by better enforcement (*Scenario II*), by investing in monitoring and health impact assessment (*Scenario III*), we can hope for a more significant betterment of indoor air quality, that is likely to extend the average life expectancy (at birth) of the residents by one third of year (Figure 13). We need to treat these numbers with caution because of the uncertainty of some inputs. Yet it is clear, however, that the best results by far are only made possible via combining the above policies with a drastic reduction in outdoor air pollution (*Scenario IV*).



Scenario I	fuel and stove prices
Scenario II	+ stove subsidies and enforcement
Scenario III	+ monitoring and HIA
Scenario IV	+ outdoor and ventilation

Figure 12 - Household air pollution: A comparison of the outcomes of scenarios by 2030



Scenario I	fuel and stove prices
Scenario II	+ stove subsidies and enforcement
Scenario III	+ monitoring and HIA
Scenario IV	+ outdoor and ventilation

Figure 13 - Life expectancy: A comparison of the outcomes of scenarios by 2030

Insights from modelling

Merely redirecting fuel subsidies to cleaner fuels does not go far in the way of better indoor air. However, by implementing a concerted set of policies on various fronts, an improvement in the order of several months in average life expectancy is made possible by 2030.

So far, these results were probably to be expected and unsurprising. What is perhaps more striking is that even the best results attained through solely indoor air related policies (*Scenario III*), are still far above the WHO guidelines for acceptable levels of exposure to air pollution (the thin purple line at 10 $\mu g/m^3$ in Figure 11).

Insights from modelling

Results from combining merely indoor air related policies are underwhelming. This points to the fact that without tackling the sources of outdoor air pollution, it would not be possible to get indoor air pollution closer to acceptable levels.

6.2.2.1 Short-term vs. long-term policies

Figure 14 zooms in on the projected behaviour of the *number of households owning clean stoves* between now and 2025 for *Scenarios II & III*, still using the earlier colour coding (dark green for *Scenario II* and light green for *Scenario III*). Note that the only difference between these two scenarios was that the share of the budget allocated to monitoring and health impact assessment is zero in the former and as high as 15 percent (by 2023) in the latter.

Under close inspection, one can see that the curve for the more comprehensive scenario starts slightly lower, but then crosses over and above *Scenario II* around year 2022, increasingly outperforming it as we move forward in time. This somewhat counterintuitive behaviour has to do with the inherently opposite nature of the feedback loops (section 5.1.2) involving the two types of policies: those targeted at appliance subsidies and those targeted at data collection, research and awareness creation.

We can explain this particular behaviour with reference to the structure of the model: When we start to allocate a fraction of available funds to monitoring and health impact assessment (starting at 5 percent and going up to 15 percent for each), this inevitably comes at the expense of being slightly smaller subsidies for clean stoves to the population; hence *Scenario III* curve lying a touch below *Scenario II*. Over time, however, the results from the monitoring and health impact assessment studies start to generate concern over the quality of the air slum residents breathe, its consequences on their health and the subsequent burden of healthcare costs on the public purse. Local politicians and activists would then be in a position to leverage this increased awareness to demand and access more funds in order to combat indoor air pollution. This would enlarge the size of the 'pie', which means that even though an increasing share of these funds is redirected from providing subsidised appliances to funding monitoring and health impact assessment, in due course there will be more and more money available for providing subsidised appliances. Due to the reinforcing nature of the dynamics involving monitoring and health impact assessments, the gap between the two scenarios grows increasingly wider. How wide it will grow and how much the pie grows depends on how intensely public awareness will translate into concern and expenditures. We deliberately kept our estimates conservative, thus there might be higher leverage.

Such *worse-before-better* situation is common in policymaking, where oftentimes short and long term goals do not necessarily align. In such circumstances, it is not unusual for policy-maker to aim for the best-possible short term results, inevitably sacrificing the system's long-term capacity to improve itself.

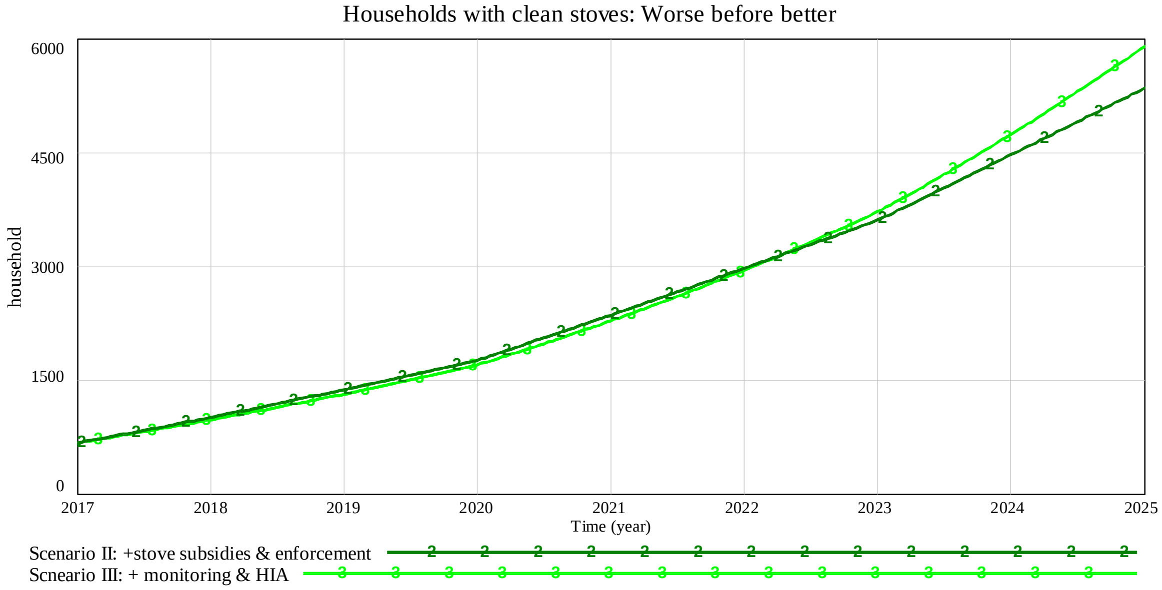


Figure 14: Worse-before-better behaviour in the prevalence of clean stoves

Insights from modelling

Redirecting a share of available funds from provision of subsidised appliances to monitoring and health impact assessment generates a 'worse-before-better' behaviour, with increasingly better long-term results in terms of indoor air quality.

6.2.2.2 Synergies among policies

We saw earlier that our most comprehensive portfolio of exclusively indoor related policies, *Scenario III*, yields a 15 percent improvement in *household air pollution* and an additional 0.34 year of average life expectancy by 2030. But what is the contribution of each single policy in this total progress? Figure 15 outlines these contributions for our two indicators of interest.

From this graph, it becomes clear that the two policies with the highest contributions in this scenario are (i) redirecting funds from clean lighting to clean stoves (blue bars at the bottom) and (ii) redistributing subsidies from kerosene to LPG while lowering the price of clean stoves (yellow bars in the middle). More interestingly, there is no direct contribution from investments in monitoring or health impact assessment (HIA): There are no orange or grey bars to be seen. This is probably the reason why the hypothetical policymaker sees no clear reason to invest in these. What the policymaker is likely to overlook, however, is the existence of the green bars of *synergy*; the 'invisible' but substantial contributor to improvement and the fact that synergies are activated and invigorated as a result of monitoring and health impact assessment. In our scenario with no funds allocated to these, the contributions from synergies would go down from 5.3 percent to 1.9 percent for *household air pollution* and from 0.12 to 0.05 years for *life expectancy*.

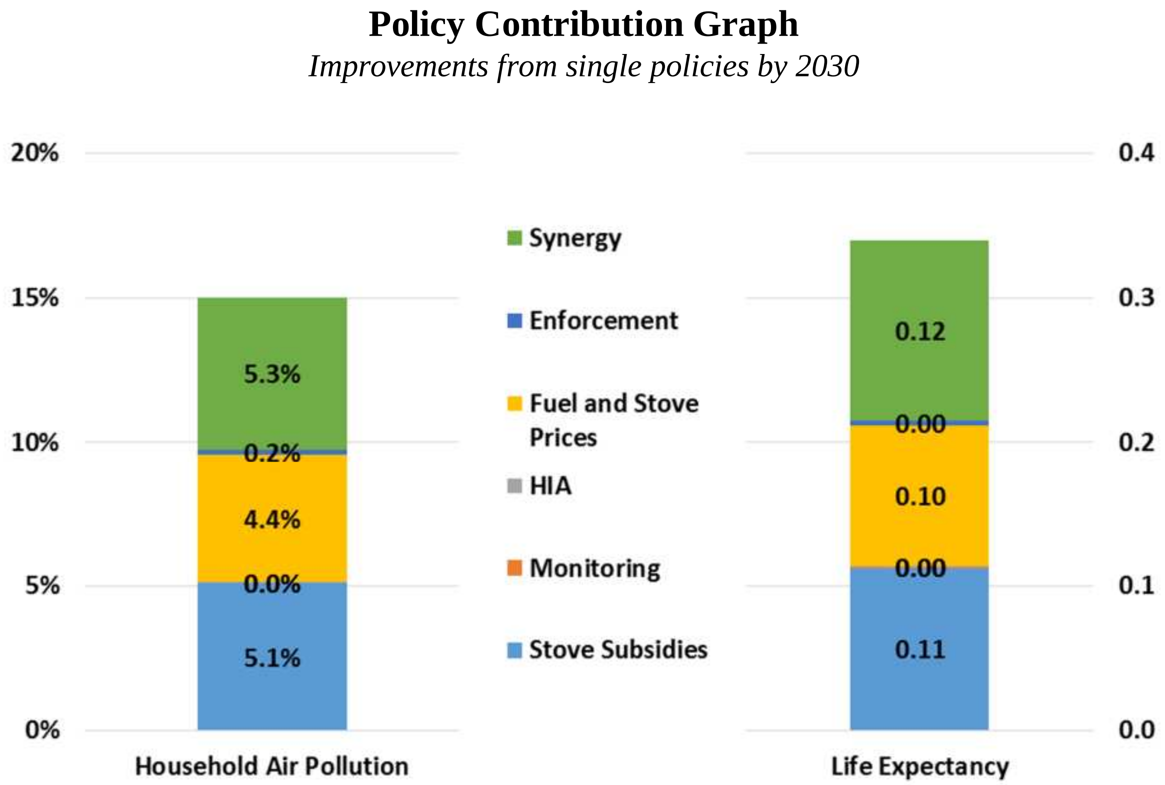


Figure 15: Improvement over Base Run by the end of the simulation; Household Air Pollution and Life Expectancy

Once again, this has to do with the *reinforcing* nature of the *R1* and *R2* feedback loops described in *Section 5.1.2*. Generally, such loops have the potential to create synergies in systems; and were it not for the existence of other stabilising forces and limits to growth within the system, these synergies could generate exponential growth. Reinforcing cycles do not always turn in our favour, but when they do, as in this case, it is wise to invest in setting them in motion.

Insights from modelling

Investments in monitoring and health impact assessment, although not directly contributing to improvements in indoor air quality, have the potential to trigger reinforcing mechanisms that create synergies among existing policies and elevate our return on investment.

7 Discussion and conclusions

7.1 Recommendations

While *Housing in Nairobi's Informal Settlements (HINIS)* was a relatively short pilot, and although there was not an abundance of numerical data for parameterisation, calibration and validation of the quantitative System Dynamics model, which makes the model lean in an exploratory direction, still a number of well-founded, non-trivial and useful insights emerged as a results of this practice. We saw, for instance, that under business-as-usual, the current trend of slowly improving indoor air quality would soon come to a halt due to the saturation of the take-up of electric lighting and the extremely sluggish rate of take-up of clean stoves. This should be taken as a warning sign that if we are to aim for reaching WHO standards in terms of acceptable PM2.5 levels, a drastic acceleration in the take-up of clean stoves will be needed.

We saw how single policies hardly make any difference and we observed how a concerted portfolio of programmes promises considerably more visible improvements. However, our projections – without investing unfounded faith in their point-accuracy – showed that even with a comprehensive package of policies, there is little hope to close the gap between status quo and WHO guidelines for indoor air pollution by 2030. This is because even with zero indoor sources of pollution, high outdoor pollution would still degrade the indoor environment. Our engagement with the community led us to believe that arriving anywhere near WHO guidelines requires addressing sources of outdoor air pollution, such as neighbouring dumpsites, but also industrial and road pollution in parallel to indoor air pollution.

Our conceptualisation of the problem, which was a result of a participatory multi-stakeholder approach, points to the potentially high impact of working towards raising the public's and the government's awareness and concern about indoor air pollution and its consequences for residents' health and in particular its role in causing serious health issues in children. In order to achieve this, our study suggests diverting some of the available budget (however big or small it is) to indoor air quality monitoring and health impact assessment studies, in order to 'close the loop' and bring the issue of indoor air quality higher up on the list of public/government priorities. Such investments, due to the self-reinforcing nature of the dynamics involved, can entail high return on investment, as the policymaker would be able to leverage the results of such studies in order to enlarge 'the size of the pie' of available money and resources.

However, one must recognise that redirecting investments towards monitoring and health impact assessments is likely to give slightly-worse-before-better results due to the time it takes before these policies pay off, as we observed in the *Results* section (see Figure 14). This delay may persist for a politician's term. It is important to recognise this in order not to be discouraged and not to prematurely rule out such longer-term policies, but also to be realistic about the difficulties of their implementation. After a while, once the mechanisms triggered by monitoring and health impact assessment studies take off, they have the potential to create substantial synergies among other policies, multiplying their effectiveness in bringing down indoor air pollution.

It is also important to note that the large majority of slum residents are not covered by the national health insurance system (NHIF) and primarily pay for their health expenses out-of-pocket. Therefore, preventive healthcare, subsidies for cookstoves and health impact assessments paid out of the healthcare budget might not actually reduce long-term healthcare costs for the same department. Economic benefits of improved health would need to be linked with sectors such as economic planning in order to identify synergies and better distribute preventive healthcare costs.

7.2 Indoor air pollution as a topic of non-attention

In order for indoor air pollution to be addressed, it has to move into the centre of the public's and decision-makers' attention. But when we asked workshop participants to articulate their hopes for Nairobi slums, only one participant mentioned the reduction of indoor air pollution: '*To provide every single household with free cooking stoves and the removal of indoor air pollution.*' The informal nature of slums, land ownership, services and waste management were higher on people's agenda. Nevertheless, for a sub-group of stakeholders indoor air pollution was sufficiently important to attend two full workshop days. In addition, the residents who we met in focus groups recognised it as an important topic and stated that more education on the drastic consequences of indoor air pollution is required. Thus, there exists a puzzle between the importance that some attribute to the issue of indoor air pollution and the little attention it generally receives.

This bears similarity with how the issue of air pollution was dealt with in highly industrial countries several decades ago. For example, US city and county administrators were perceived to support air pollution control, but ethnic and civil groups as well as organisations were perceived to not pay any attention (Crenson, 1971). Today's situation in Kenya and Nairobi is similar because no NGO directly addresses air pollution. Yet, some academics and government representatives are aware of the importance of the topic, but find it difficult to put the topic on the agenda because of lacking public support.

This paper has extensively discussed the underlying causal mechanism (Figure 6 on page 16). The reinforcing nature of loops *R1: Monitoring* and *R2: HIA* locks the system in a vicious spiral of a lack of knowledge about pollution and its health consequences, non-attention, lack of resources for the issue and for further investigation. The modelling of the scenarios showed that triggering these reinforcing mechanisms can create leverage in the system. They re-allocate resources to indoor air pollution and additionally enlarge the size of the pie available. Yet, this means that indoor air pollution will then also fight with all the other issues for resources, acting as a serious constraint. In addition, the success depends on the strength of the relationship between attention, concern and expenditure. Work on reducing the limiting factors is needed so that these reinforcing feedback loops can fully work and trigger repetitive momentum towards a higher focus on the issue.

The residents reported the difficulties of getting heard on this and other issues. This creates a further vicious cycle of public attention and concern. Stakeholders raised socio-economic empowerment with regards to raising the earning power of slum residents as a means to break this cycle. It would improve their incomes and subsequently their ability to live in better environments and probably spur them to invest in cleaner cooking and lighting devices. The hopes expressed by stakeholders challenge government agencies and other stakeholders to have equity as a central theme in their policies and programmes. For example, governance issues would require an equity lens to ensure no section of the city is left behind in programmes and strategies.

The limited attention the indoor air pollution issue has received so far directly influenced this project and modelling work. As data collection had not been considered important, we lack reliable data in many areas that would be required for more detailed recommendations to emerge from the modelling. Thus increased investments in (indoor) air pollution would increase the precision of scientific evidence, and this evidence would hopefully make it easier to agree on needed policies.

7.3 Impact, limitations and future work

The participatory process used in the HINIS project brought together stakeholders from different sectors such as cook stove manufacturers and the policy sector that all have direct impact on households. For instance while residents spoke of prohibitive cost of cleaner fuels and stoves as being behind their persistent use of dirty fuels, it was clear that there were other relevant players such as the current energy regulation policy that has introduced pricing controls of fuels such as kerosene but not that of liquefied petroleum gas (LPG). It thus helped draw a multi-faceted picture of indoor air pollution and brought home to stakeholders the rigorous process of developing a dynamic model. Its gradual development also demystified the complex inter-linkages of sectors. One of the impacts of these workshops is the raising of participants' awareness on indoor air pollution and the inter-related factors. This may help awakening and mobilising the public's attention attention.

Yet, it is important to recognise the limitations imposed on this study due to a shortage of available time-series data on such key variables such as indoor and outdoor air pollution and past expenditures on related policies, among other variables. This points to the crucial importance of investing in the collection of data over time, as it is hard to manage what you have not measured. Such data would then allow more rigorous testing of uncertainties, e.g. through sensitivity simulations, so that more operational recommendations can be given beyond the creation of behaviour modes.

Another key limitation of this study is the completely exogenous treatment of the level of *outdoor air pollution*, which we included as a scenario variable whose future value was to be set by the user. Yet, the effects of policies such as the fuel taxes and subsidies also affect outdoor air pollution through transport, etc. For a more realistic treatment of the problem of indoor air pollution, it would thus be desired to endogenously include how indoor pollutants and our simulated policies interact with both indoor and outdoor air pollution.

Finally, we suggest to more closely focus on implementation. This includes examining the interrelationships between communities, the public, organisations and government on the issue of indoor air pollution. Our workshop discussions hint to their quite different goals. While we spent an afternoon during the final workshop to discuss implementation issues and potential unintended consequences of policies, such practical aspects warrant a more thorough examination and inclusion in the model.

Acknowledgements

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Appendix

Policy/Scenario variable	Unit	Base run	Scenario I	Scenario II	Scenario III
future share of air quality expenditure for appliance subsidies	dimensionless	98%	98%	100%	@2017: 90% @2020: 80% @2023: 70%
future share of indoor air quality expenditure for monitoring	dimensionless	2%	2%	0	@2017: 5% @2020: 10% @2023: 15%
future share of air quality expenditure for health impact assessment	dimensionless	0	0	0	@2017: 5% @2020: 10% @2023: 15%
future share of appliance subsidies for clean stoves	dimensionless	5%	5%	@2017: 50% @2020: 75% @2023: 100%	@2017: 50% @2020: 75% @2023: 100%
future price of kerosene	KSH per litre	63.4	@2017: 70 @2020: 80 @2023: 90	@2017: 70 @2020: 80 @2023: 90	@2017: 70 @2020: 80 @2023: 90
future price of LPG	KSH per 6kg cylinder	1246	@2017: 1160 @2020: 1080 @2023: 1000	@2017: 1160 @2020: 1080 @2023: 1000	@2017: 1160 @2020: 1080 @2023: 1000
future price of clean stoves	KSH per unit	5000	by 2030 linearly down to 4000	by 2030 linearly down to 4000	by 2030 linearly down to 4000
future enforcement, political will, and good governance	dimensionless (conceptualised as a 0 to 1 index)	0.25	0.25	by 2030 linearly up to 0.5	by 2030 linearly up to 0.5