Air pollution and the lung in children: the evidence for exposure and prevention measures

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Overview

Background on pollutants outdoor and indoor pollutants

Outdoor air pollution during pregnancy and lung development (short term)

Outdoor air pollution during childhood and lung development (long term)

Overview

Outdoor:

Particulate matter ($\mathbf{PM_{10}}$, $\mathbf{PM_{2.5}}$, $\mathbf{PM_1}$): carbon monoxide (CO), sulfur dioxide $(\mathbf{SO_2})$, nitrogen oxide $(\mathbf{NO_2})$, ozone $(\mathbf{O_3})$, lead, polycyclic aromatic hydrocarbons (**PAH**)

Indoor:

Tobacco smoking, biomass, gas and other fuels for cooking and heating e.g. benzene, open fire places, furnishings, building materials

Background on outdoor air pollutants

PM: particulate matter / size in µm

Origin mostly traffic and industry

Rather homogenous spatial distribution

NO_2: nitric dioxide

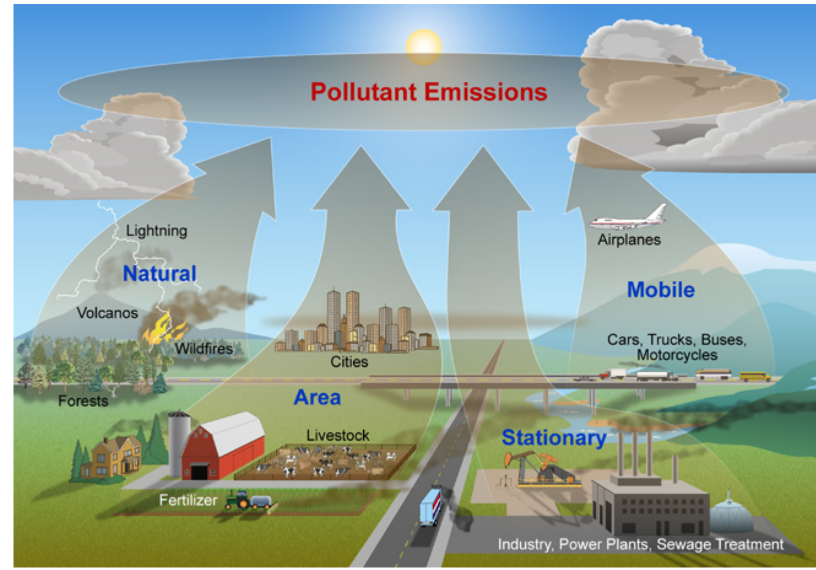
Origin mostly traffic

Usually higher close to roads

Black carbon

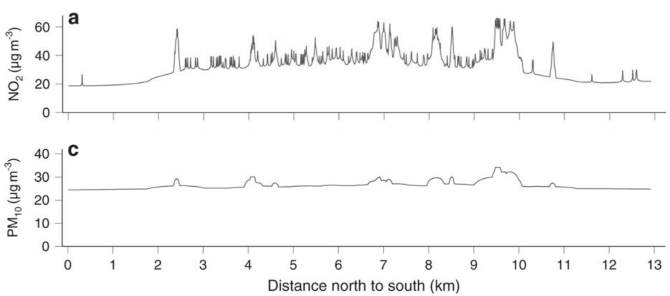
Pure carbon in several forms

Origin incomplete combustion of fuel and biomass



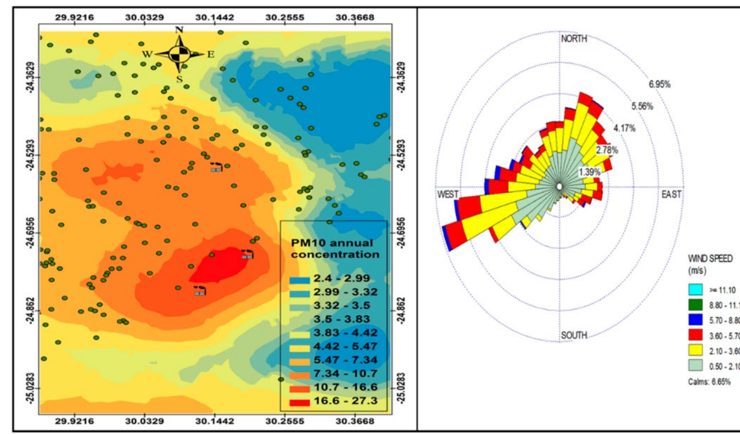
Pollutants – spatial variation

Spatial variation – Utrecht (NL)



Adapted from Schmidz et al. 2019. High resolution annual average air pollution concentration maps for the Netherlands, *Scientific Data 6:190035*

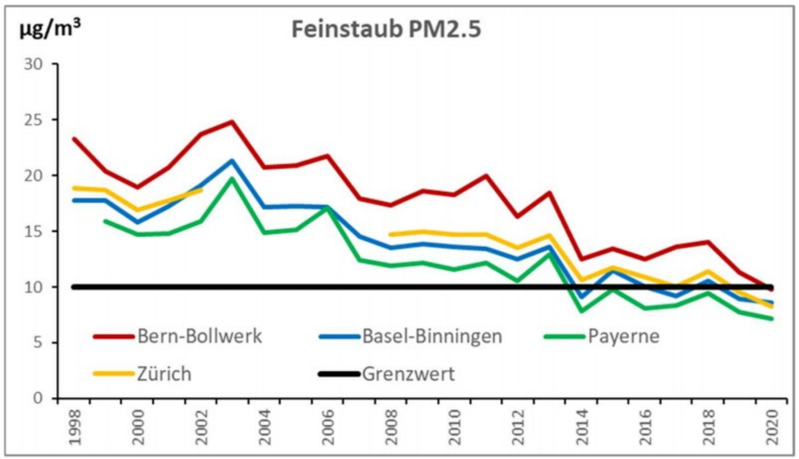
Spatial variation – Limpopo (South Africa)



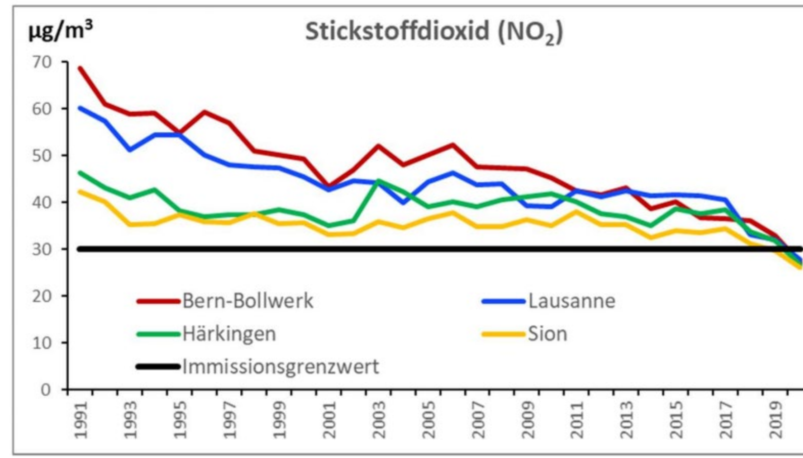
Adapted from Tshehla et al. 2019. Spatial and Temporal Variation of PM10 from Industrial Point Sources in a Rural Area in Limpopo, South Africa, *Int J Environ Res Public Health. 2019*

Pollutants – temporal variation in Switzerland

Temporal variation $PM_{2.5}$



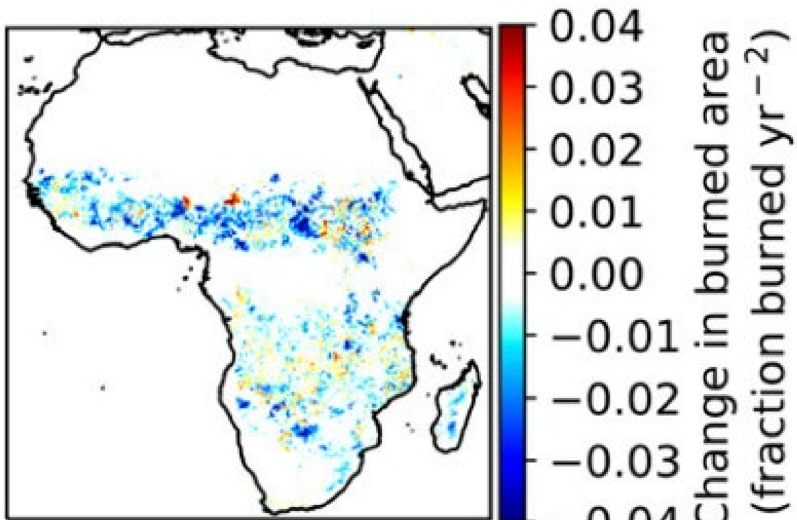
Temporal variation NO_2



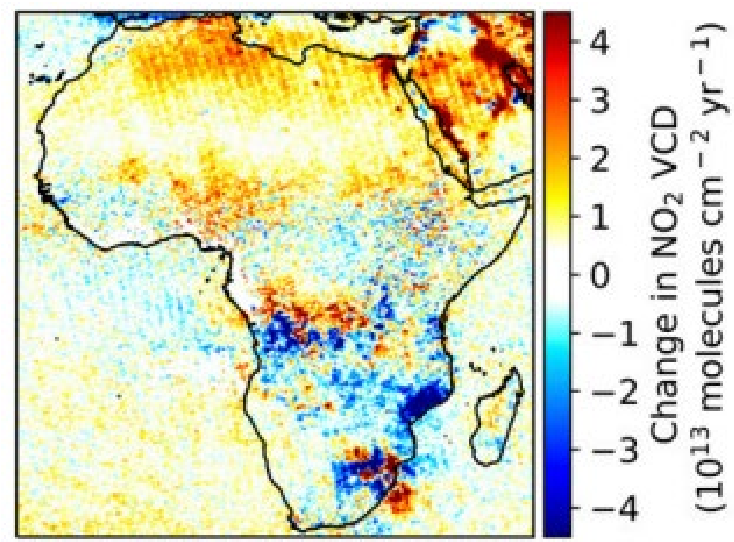
Source: NABEL, results of national measurement stations, BAFU, EMPA, *accessed 04.07.2021*

Pollutants – temporal variation in South Africa

Change in burned area (2005-2017)



Change in NO_2 (2005-2017)

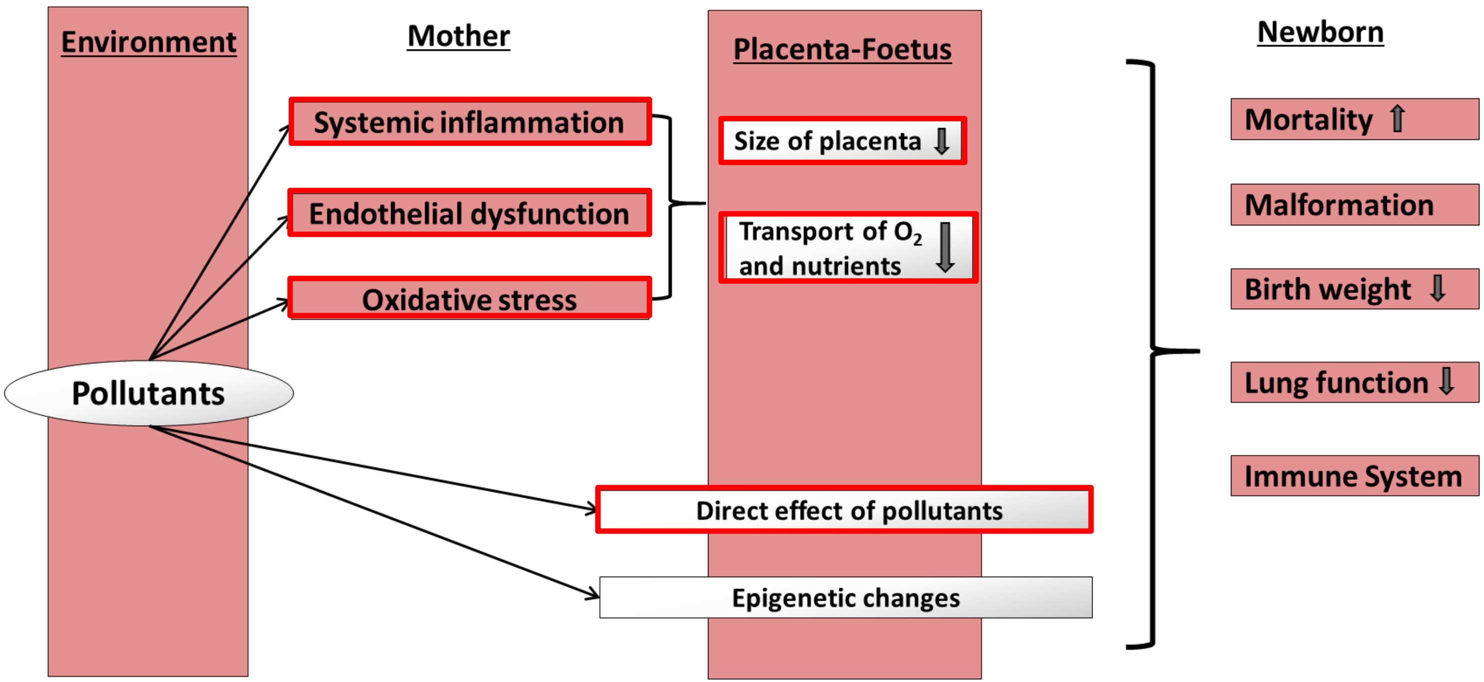


Hickman JE et al. Reductions in NO2 burden over north equatorial Africa from decline in biomass burning in spite of growing fossil fuel use, 2005 to 2017, *PNAS February 16, 2021 118 (7) e2002579118;*

Air Pollution during pregnancy: mechanisms

- Dependent on stage of development
- Systemic effect on the mother:
  - reduced placental perfusion
  - reduced nutrient exchange
- Direct toxic effect through placental transfer of pollutants (e.g., nanoparticles)
- Proinflammatory/oxidative/hormonal stress effect
- Changes to the immune system development
- Changes to lung growth and development
- Genetic interactions/epigenetic effects

Air pollution during pregnancy



Lee et al. *Epidemiology 2011,* reviewed in Slama et al. *Env Health Persp 2008*

adapted from Korten et al. *Ped Resp Rev 2017*

Infant lung function – Switzerland

241 term-born infants from the BILD cohort

Exposure towards PM_{10} and NO_2 during pregnancy

Lung function at around 4 weeks

	Basic model			Full model		
	coefficient	**CI 95%**	**p Value**	**coefficient**	**CI 95%**	**p Value**
Prenatal PM_{10} and Minute ventilation [mL/min]	**19.9**	**4.7 – 35.0**	**0.010**	**24.7**	**8.9 – 40.5**	**0.002**
Prenatal NO_2 and eNO [ppb]	**0.67**	**0.23 – 1.10**	**0.003**	**0.96**	**0.44 – 1.48**	**<0.001**

Latzin et al. *ERJ* 2009

Infant lung function – South Africa

270 term-born infants from the Drakenstein Child Health Study

Exposure towards PM_{10} during pregnancy and first year

	β-estimate (95% CI)	p-value
Prenatal		
PM_{10}		
FRC (6 weeks)	−1.9 (−4.5–0.7)	0.160
Tidal volume (6 weeks)	−0.4 (−1.3–0.6)	0.419
FRC (1 year)	−9.0 (−17.2– −0.9)	0.032#
Postnatal		
PM_{10}		
FRC (1 year)	−4.3 (−12.5–3.9)	0.304
Tidal volume (1 year)	−2.9 (−5.4– −0.5)	0.022#
LRTI (in the first year)	0.0 (−0.3–0.4)	0.799

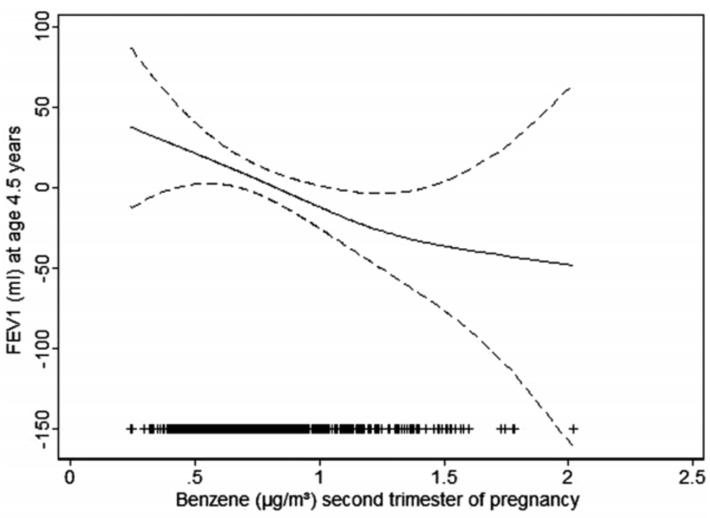
Hüls et al. *ERJ* 2020

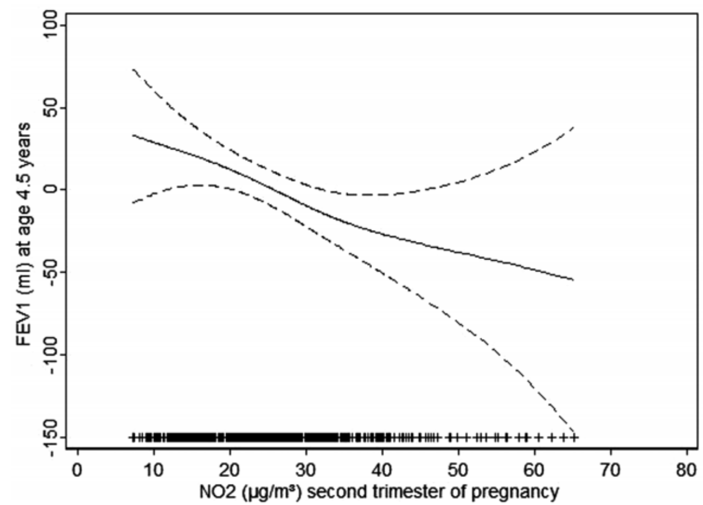
Childhood lung function– Spain

620 term-born infants from the INfancia y Medio Ambiente (INMA) cohort

Exposure towards benzene and NO_2 during pregnancy (second trimester)

Lung function at around 4.5 years, outcome FEV1





Eva Morales et al. *Thorax 2015;70:64-73*

Effects of long-term air pollution exposure during childhood

UKBB excellent & caring

- Development of chronic lung problems in children
- Reduced lung function

  (z.B. Env. Research **1989**; 50: 309-321)

- PMx → development of bronchitis, chronic cough, less from asthma

  (J Air Poll Control Assoc. 1982; 32: 937-942)

  (Schweiz: AJRCCM 1997; 155:1042-1049)

- Ozone → decline in lung function

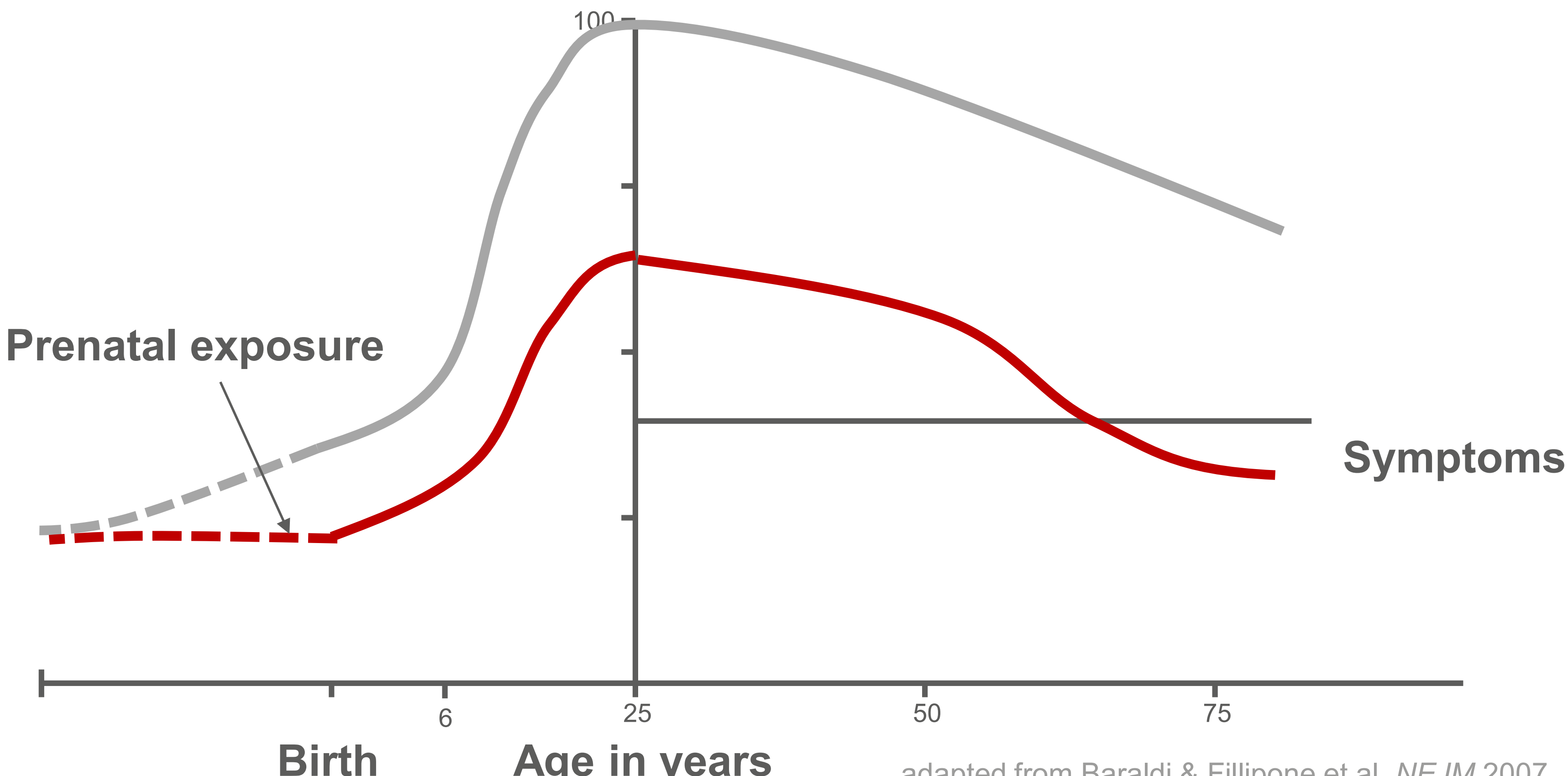
  (Env. Research 1997; 72: 8-23)

- Road traffic (outdoor NO_2 + polycyclic aromatic hydrocarbons KWS, Diesel) correlated with asthma, hay fever, sensitisaiton to airborne allergens

  (ERJ 1997; 10: 2275-8)

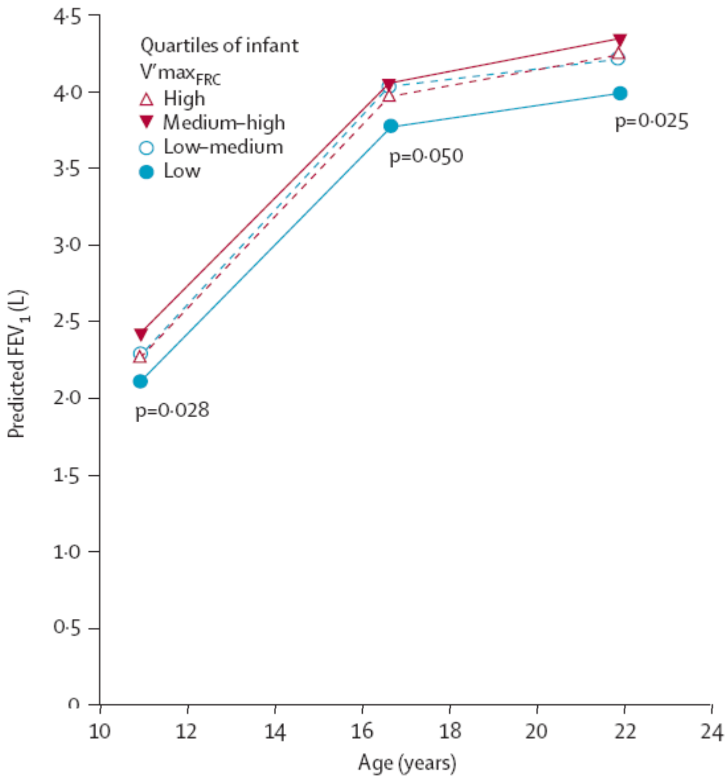
  (Epidemiology 2000; 11: 64-70)

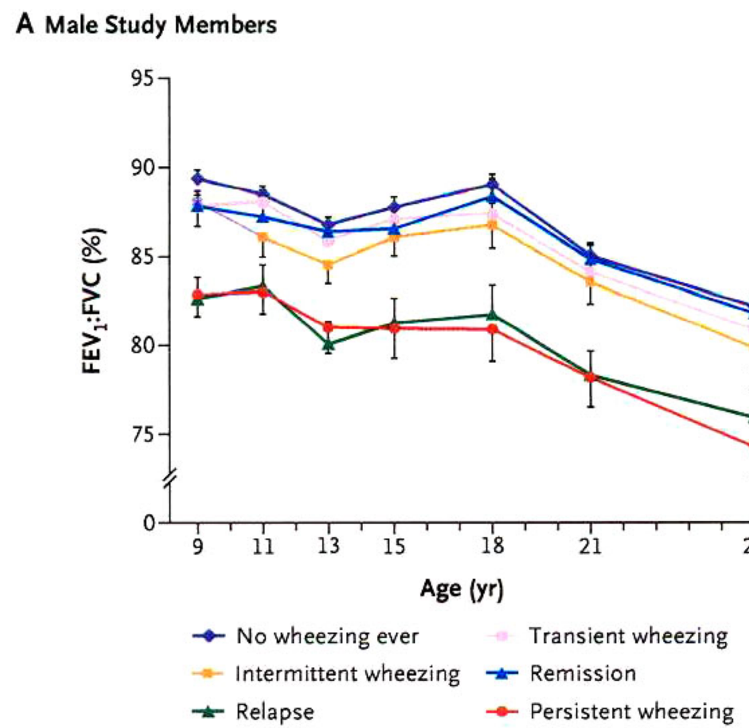
Lung development and prenatal exposure



adapted from Baraldi & Fillipone et al. *NEJM* 2007

‘Tracking’ of lung function during development

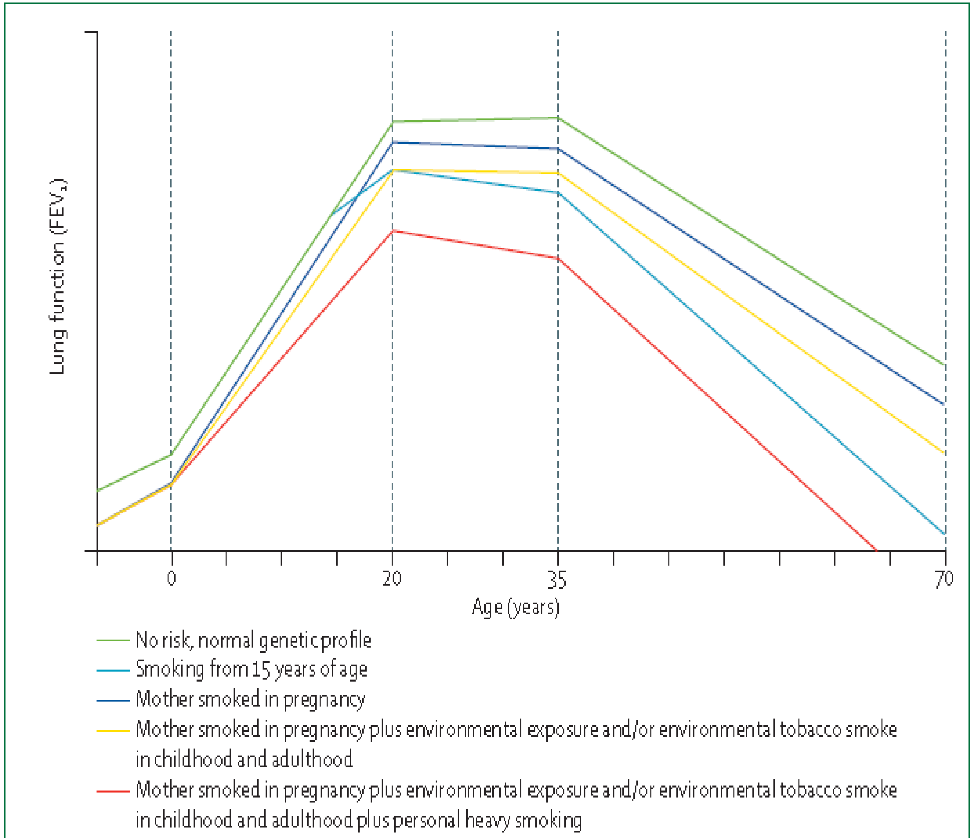




Stern et al. Lancet 2007;370:758–64

Sears MR et al. N Engl J Med 2003;349:1414-22

Early childhood risk factors associated with functional development throughout life



Childhood risk factors for the decline in lung function in adulthood (28–73 yrs.)

- **Infants born during winter**
- **Smoking mothers**
- **Older mothers**

Dravda J et al. SAPALDIA PlosOne 2016; DOI 10.1371

Summarized in e.g. Postma D et al. *Lancet 2015;385:899–909*

Influence of long-lerm exposure on lung development

UKBB excellent & caring

Air pollution in Poland is associated with reduced lung function during development

(e.g.. Env Health Perspect 1999; 107: 669-674)

PM_{10} particle concentration is inversley correlated to lung function development during childhood

(ERJ 2002; 19: 838-845)

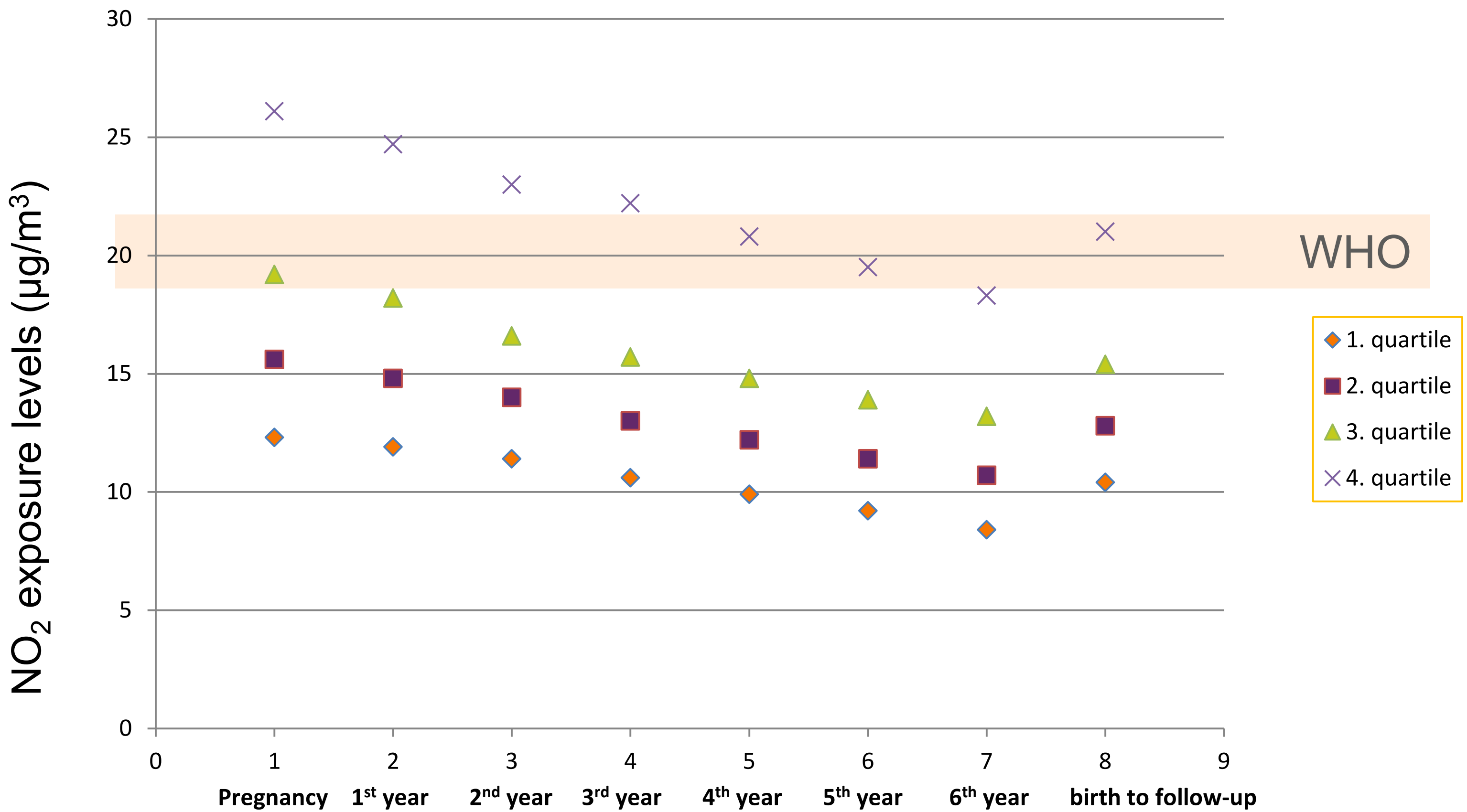
Children who move away from polluted areas can return to normal lung functional development (and vice versa)

(AJRCCM; 2001; 164: 2067-72)

Improvement in air quality → reduced clinical symptoms

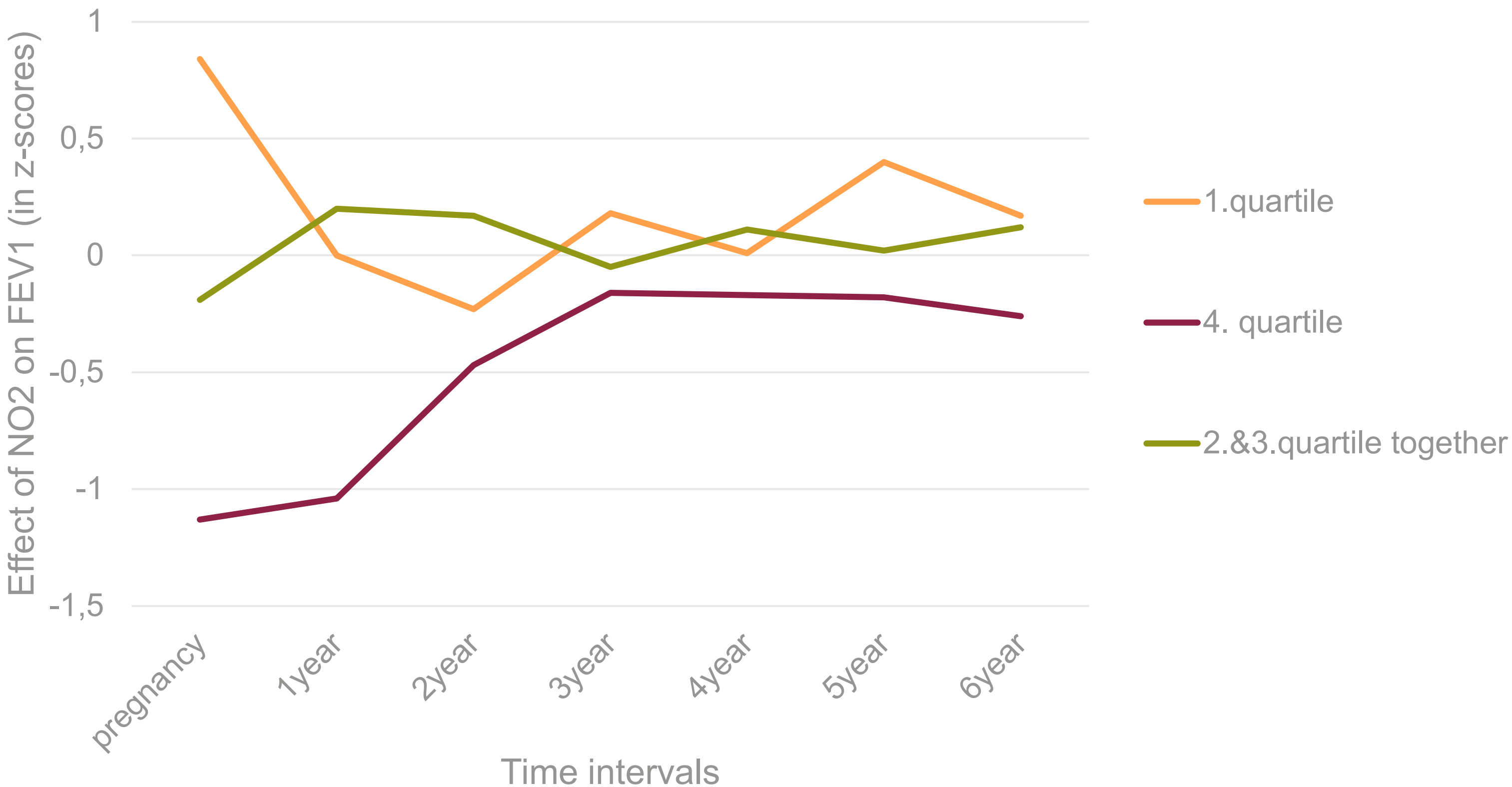
(AJRCCM; 2000; 161: 1930-36)

Early fife low level air pollution and lung functional growth



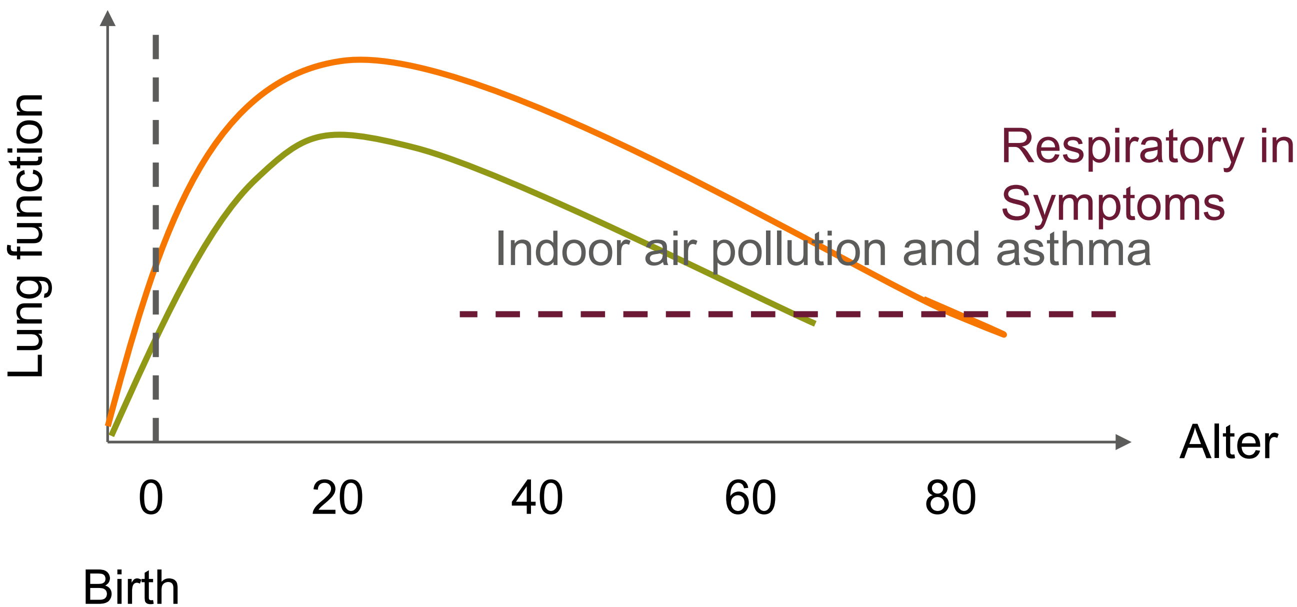
Usemann & Decrue et al. *Envir International 2019*

Early low level air pollution and lung growth



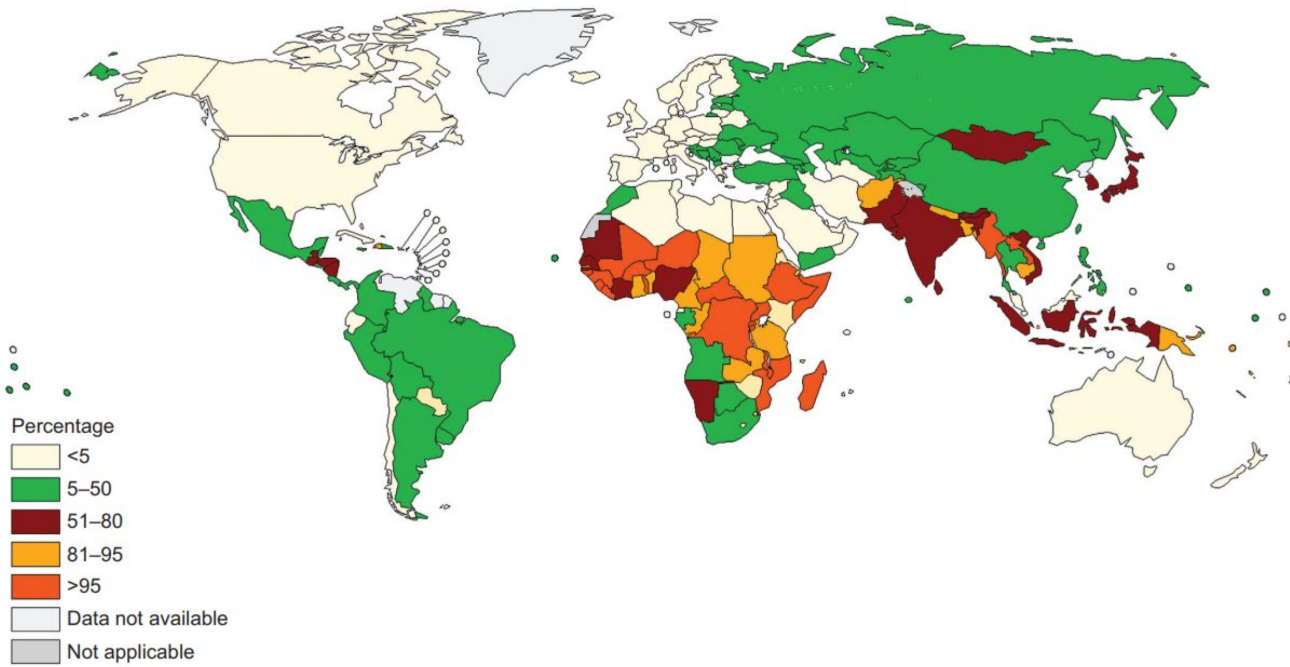
Usemann & Decrue et al. *Envir International 2019*

Long-term effects on health developement



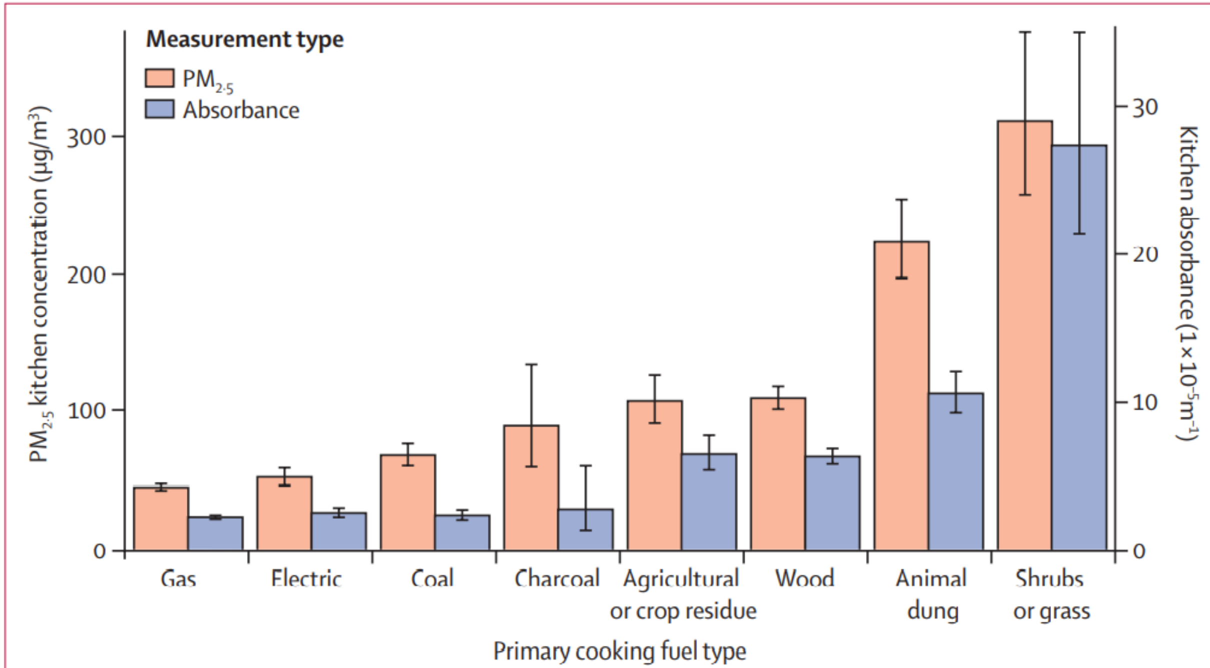
Commentary Frey U & Usemann J. *Lancet Planet Health. 2019 Feb 5*

Percentage of solid fuel use



O.P. Kurmi et al. *ERJ 2012*

Exposure levels of indoor air pollution



Switzerland: $PM_{2.5}$ ca 12.1 µg/m3

Meier R et al. M et al. *Environ Int. 2015 Sep;82:85-91* Shupler M et al. *Lancet Planet Health 2020*

Indoor air pollution and asthma

TABLE 1 Studies of the relationship between biomass exposure and asthma prevalence

First author [ref.]	Country	Fuel type	Sample size	Sample type	Diagnosis criteria	Effect size OR (95% CI)
Mohamed [95]	Kenya	Biomass and clean fuel	77 cases and 77 controls	Children aged 9–11 yrs	Adapted from IUATLD	2.5 (2.0–6.4)
Azizi [96]	Malaysia	Wood and kerosene	158 cases and 201 control	Children aged 1 month to 5 yrs	Hospital-based doctor diagnosed	1.4 (0.60–3.60) wood and 0.9 (0.50–1.60) kerosene
Melsom [97]	Nepal	Biomass and clean fuel	121 cases and 126 control	Children aged 11–17 yrs	ISAAC criteria	2.2 (1.0–4.5)
Mishra [98]	India	Biomass and clean fuel	38595 subjects	Adults aged ⩾60 yrs	Based on interviewee replying yes to asthma questionnaire	1.59 (1.30–1.94)
Schei [99]	Guatemala	Wood	1058 subjects	Children aged 4–6 yrs	ISAAC criteria	1.8 (0.76–4.19)

Conclusion

Associations between exposure towards air pollution and impaired lung development are relatively clear

Stronger effects seem to exist during periods of fastest lung growth

Reduction in exposure is associated with improved lung growth

Exposure below WHO cut-offs still have negative effects on lung function

Combination of risk factors attenuates detrimental effects on lung growth

Modifiable risk factors should further be reduced

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Thank you very much for your attention

Air Pollution and the Lung in Children

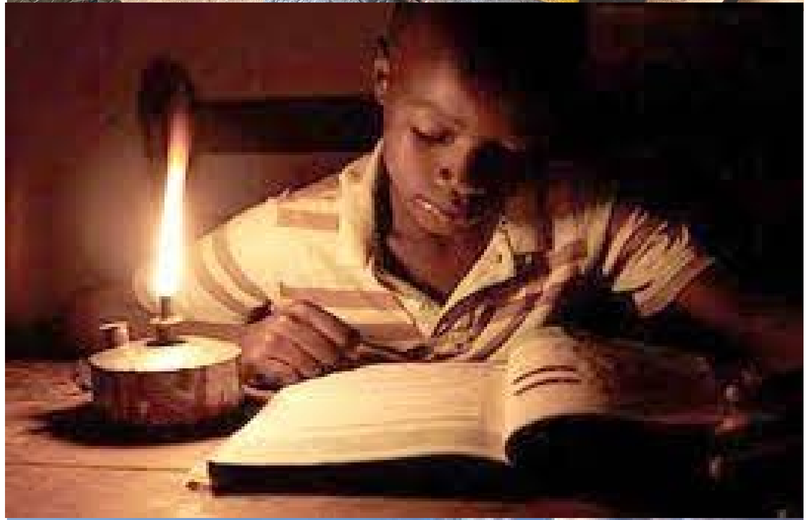
Prevention Measures

Rebecca Nantanda

PATS & ERS Paediatric Webinar

Tuesday 13th July 2021



Common sources of air pollution

Why intervene?

- Air pollution has life long implications (intra-uterine life – adulthood)

- Growing lungs (and other body organs) are very vulnerable to effects of air pollution

  Impact on overall growth and development and the potential of affected children

- Air pollution is directly linked to killer diseases

  50% of pneumonia deaths linked to air pollution

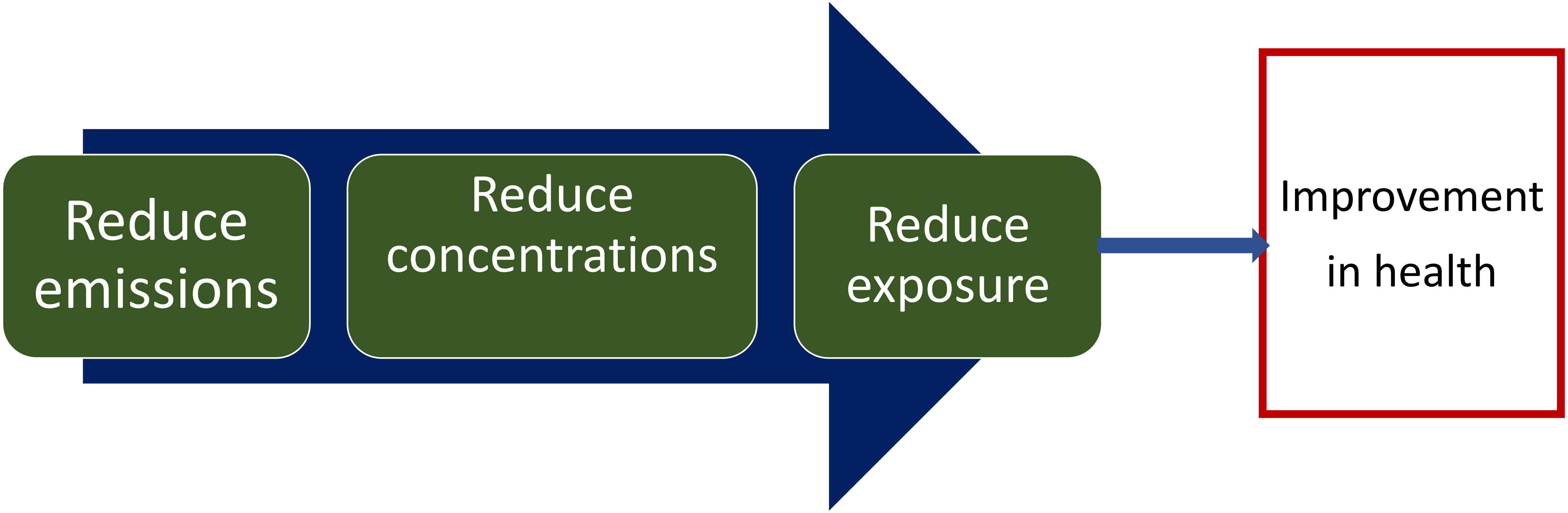
- Reducing air pollution leads to improvement in lung function

Clean the Air for Children UNICEF 2016

How to protect children from air pollution

- Invest in sustainable cleaner energy sources
- Reduce on fossil fuel combustion
- Minimize children's exposure to polluted air
- Improve air pollution monitoring and its link with children's health
- Strengthen children's overall health increased resilience to effects of air pollution

Approach to interventions

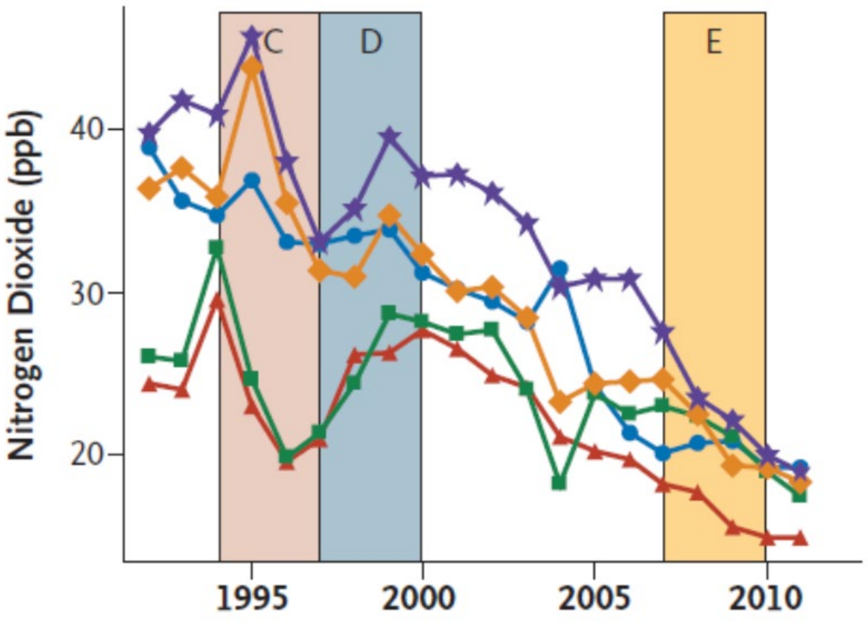


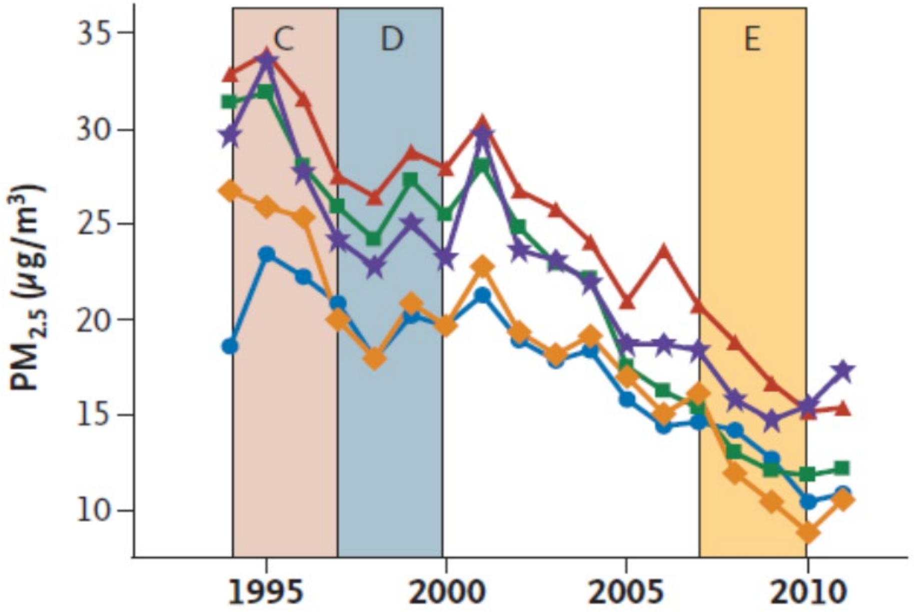
The NEW ENGLAND JOURNAL of MEDICINE

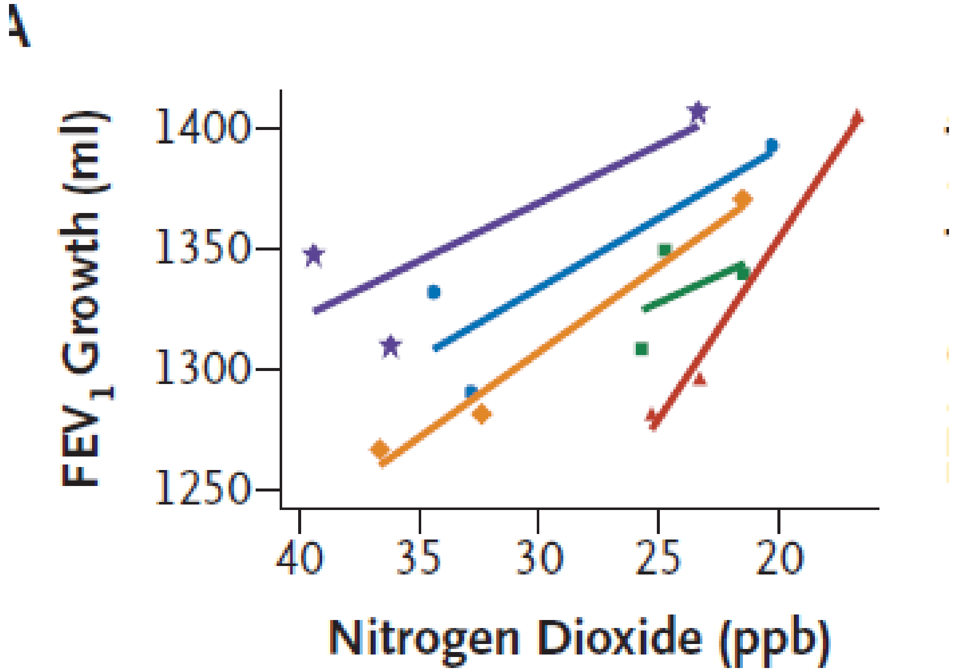
ESTABLISHED IN 1812 MARCH 5, 2015 VOL. 372 NO. 10

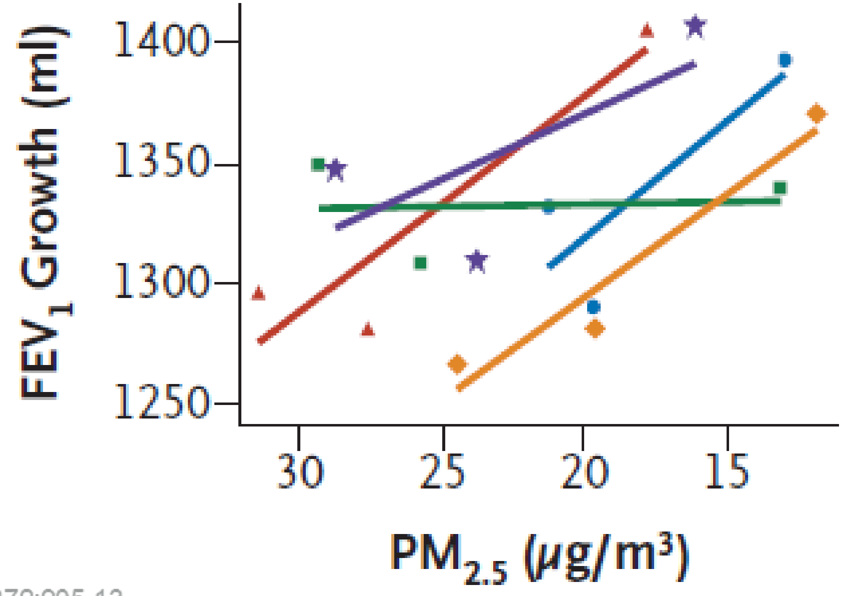
Association of Improved Air Quality with Lung Development in Children

W. James Gauderman, Ph.D., Robert Urman, M.S., Edward Avol, M.S., Kiros Berhane, Ph.D., Rob McConnell, M.D., Edward Rappaport, M.S., Roger Chang, Ph.D., Fred Lurmann, M.S., and Frank Gilliland, M.D., Ph.D.









Gauderman et al. NEJM 2015;372:905-13


Photo Credit: Ben West


Photo Credit: Michael Benanav

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

Global Alliance for Clean Cookstoves

SAVE LIVES | IMPROVE LIVELIHOODS | EMPOWER WOMEN | COMBAT CLIMATE CHANGE

CLEAN COOKSTOVES

<u>THE RESPIRE TRIAL: Guatemala highlands</u>

534 households with a pregnant woman or infant

randomized to receive a chimney stove or retain the open fire

Primary outcome: incidence of pneumonia in children

<u>Results</u>

- Non-significant reduction in incidence of physician-diagnosed pneumonia
- Significant reduction in physician-diagnosed severe pneumonia (RR 0.67; 95% CI 0.45 to 0.98)

Smith, K.R., et al. Lancet 2011, Heinzerling AP., et al. Thorax 2016

Cooking and Pneumonia Study (CAPS)

A cleaner burning biomass-fuelled cookstove intervention to prevent pneumonia in children under 5 years old in rural Malawi (the Cooking and Pneumonia Study): a cluster randomised controlled trial

Kevin Mortimer, Chifundo B Ndamala, Andrew W Naunje, Jullita Malava, Cynthia Katundu, William Weston, Deborah Havens, Daniel Pope, Nigel G Bruce, Moffat Nyirenda, Duolao Wang, Amelia Crampin, Jonathan Grigg, John Balmes, Stephen B Gordon

oa

Summary

Background WHO estimates exposure to air pollution from cooking with solid fuels is associated with over 4 million premature deaths worldwide every year including half a million children under the age of 5 years from pneumonia. We hypothesised that replacing open fires with cleaner burning biomass-fuelled cookstoves would reduce pneumonia incidence in young children.

Methods We did a community-level open cluster randomised controlled trial to compare the effects of a cleaner burning biomass-fuelled cookstove intervention to continuation of open fire cooking on pneumonia in children living in two rural districts, Chikhwawa and Karonga, of Malawi. Clusters were randomly allocated to intervention and control groups using a computer-generated randomisation schedule with stratification by site, distance from health centre, and size of cluster. Within clusters, households with a child under the age of 4·5 years were eligible. Intervention households received two biomass-fuelled cookstoves and a solar panel. The primary outcome was WHO Integrated Management of Childhood Illness (IMCI)-defined pneumonia episodes in children under 5 years of age. Efficacy and safety analyses were by intention to treat. The trial is registered with ISRCTN, number ISRCTN59448623.

Findings We enrolled 10 750 children from 8626 households across 150 clusters between Dec 9, 2013, and Feb 28, 2016. 10 543 children from 8470 households contributed 15 991 child-years of follow-up data to the intention-to-treat analysis. The IMCI pneumonia incidence rate in the intervention group was 15·76 (95% CI 14·89–16·63) per 100 child-years and in the control group 15·58 (95% CI 14·72–16·45) per 100 child-years, with an intervention versus control incidence rate ratio (IRR) of 1·01 (95% CI 0·91–1·13; p=0·80). Cooking-related serious adverse events (burns) were seen in 19 children; nine in the intervention and ten (one death) in the control group (IRR 0·91 [95% CI 0·37–2·23]; p=0·83).

Interpretation We found no evidence that an intervention comprising cleaner burning biomass-fuelled cookstoves reduced the risk of pneumonia in young children in rural Malawi. Effective strategies to reduce the adverse health effects of household air pollution are needed.

Funding Medical Research Council, UK Department for International Development, and Wellcome Trust.

Lancet 2017; 389: 167–75

Published Online December 6, 2016 http://dx.doi.org/10.1016/S0140-6736(16)32507-7

See Comment page 130

Malawi Liverpool Wellcome Trust Programme, Blantyre, Malawi (K Mortimer PhD, C B Ndamala Dip, A W Naunje, W Weston MBChB, Prof S B Gordon MD); **Liverpool School of Tropical Medicine, Liverpool, UK** (K Mortimer, W Weston, D Havens DO, Prof D Wang PhD, Prof S B Gordon); **Malawi Epidemiology and Intervention Research Unit, Chilumba, Malawi** (J Malava MPH, C Katundu Dip, Prof M Nyirenda PhD, A Crampin MPH); **University of Liverpool, Liverpool, UK** (D Pope PhD, Prof N G Bruce PhD); **London School of Hygiene & Tropical Medicine, London, UK** (Prof M Nyirenda, A Crampin); **Queen Mary University of London, London, UK** (Prof J Grigg MD); **University of**

Rwanda: High efficiency wood burning stove

- 2174 children, 5934 episodes of ARI
- Primary outcome –caregiver reported ARI
- Measured personal exposure for the cooks and child
- 25% reduction in prevalence of ARI, statistically significant PR=0.75 (0.60-0.93), p=0.009 (broad definition of pneumonia)
- No statistically significant difference –DHS –defined pneumonia, current pneumonia
- No statistically significant difference in mean PM2.5
- Decline in clean cookstove use from 81.2% to 64.4%
- Increase in use of traditional stove use from 24.1% t0 49.4%

Kiby MA,et al. PLoS Med 2019

LPG use in the pilot study in India: HAPIN trial

Enrolled 41 women

No previous use of LPG,

Gestation weeks 9 to <20 weeks

Design: Before and after study

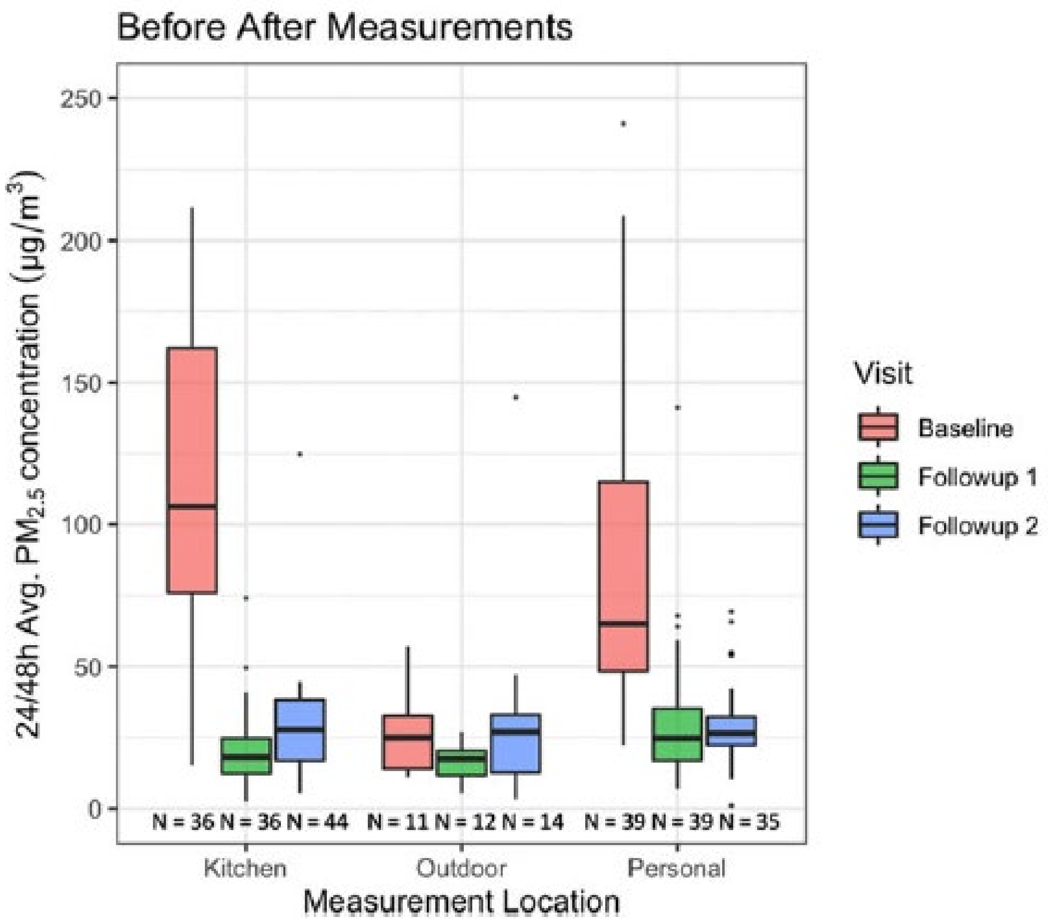
Intervention : Free of cost LPG, 100% adherence

Measurements:

Personal, kitchen and outdoor $PM_{2.5}$

baseline, 1 and 2 months

- **Kitchen=93% reduction in mean $PM_{2.5}$**
- **Personal =78% reduction**



Sambandam S, et al BMC Public Health 2020

Effect of LPG use on cardiopulmonary outcomes: RCT in Puno, Peru

Participants: 180 rural women aged 25-64 years

Intervention package: Stove, LPG delivery for 1 year, Education and behavioural change messaging

Assessment: BP, PEF, Respiratory symptoms (SGRQ), $PM_{2.5}$ CO, BC

Adherence assessed using temperature loggers

Primary outcomes

Differences in lung function and respiratory symptoms

Results

- LPG used in 98% of the days
- No difference in lung function and respiratory symptoms

Checkley W, et al. AJRCCM 2021

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Global Public Health

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Feasibility and acceptability of a midwife-led health education strategy to reduce exposure to biomass smoke among pregnant women in Uganda, A FRESH AIR project

Rebecca Nantanda, Shamim Buteme, Sanne van Kampen, Lucy Cartwright, Jill Pooler, Andy Barton, Lynne Callaghan, Jean Mirembe, Grace Ndeezi, James K. Tumwine, Bruce Kirenga & Rupert Jones

Educational interventions: Midwife-led project in Uganda


[redacted]

HOW TO PREVENT EXPOSURE TO BIOMASS SMOKE
- Reduce the amount of time spent by the fire especially mothers and young children.
- Keep children out of the kitchen especially when the fire is producing smoke
- Do not put young babies in smoky places
- Avoid burning rubbish and leaves, recycle or dispose off plastic, leaves and other organic matter should be dug into the soil.

HOW TO PREVENT EXPOSURE TO HOUSEHOLD AIR POLLUTION
- Kitchen ventilation requires good air flow
- 2 windows
- Eves spaces
- A hood to collect smoke from fire
- A stove with a chimney
- Alternatively build a new cooking hut with good ventilation
- Avoid burning kerosene lamps, but if they are used do not let them burn all night

✓ ✓✓ ✓✓✓ ✓✓✓✓

COMMON TYPES OF COOKING METHODS, FUEL AND ALTERNATIVES THAT REDUCE SMOKE.

Fuel.
- Dry wood is better than wet wood,
- charcoal is better than dry wood
- Gas is better than charcoal

Cookers and cooking.
- Cooking with lids on pans reduces the time to boil
- Retained heat cooking – the boiling pot is put into a box and packed around with suitable materials to keep it hot for a long time.
- There are many types of new cook stoves which;
  - Burn more cleanly (more heat less smoke)
  - Use much less wood
  - Reduce burns

BENEFITS OF REDUCING EXPOSURE TO BIOMASS SMOKE/HOUSEHOLD AIR POLLUTION.
Keeping your unborn and young children away from smoke has lifelong benefits. These are:
- Healthy pregnancy
- Healthy baby
- Healthy child
- Healthy adult

KEY POINTS TO NOTE.
- Always attend ANC appointments for monitoring of your pregnancy.
- Avoid staying in the kitchen for long hours while cooking
- Keep babies and young children away from the smoke/kitchen
- The effects of the smoke may not be immediately visible but are very dangerous/harmful to the baby's/mother's health.

BIOMASS SMOKE:

What every pregnant woman and mother needs to know.

FRESH AIR UGANDA

Key findings
- Improvements in knowledge about risks of biomass smoke
- Changes made- keeping away from smoke, burying refuse
- Intent to change
- Buy solar panels, clean cookstoves
- Put chimneys on the kitchen
- Major barrier -Poverty

Policy initiatives

Country/Year	Intervention
UK	Standards and implementation of fuel quality initiated by The Quality Assured Fuel Scheme. National campaign to encourage uptake
South Africa	Encouraged investments in renewal energy through various funds, tax allowances and deductions
Namibia	Public campaign on forest conservation-reduction of fire incidences by 70%
Chile	Ministry of Environment- exchange of old stoves with new clean cookstoves
Rwanda	Banned non-biodegradable plastic bags -reduction in amount of burnt plastics

Clean the Air for Children UNICEF 2016

Urban planning

- Gazetted areas for industries
- Structural designs and operations that minimize industrial emissions
- Provision for active transport

Personal strategies

- Limit physical exertion outdoors on high pollution days
- Minimize use of highly polluted areas/roads
- Air quality alert systems

Carlsten C, et al. Eur Respir J 2020

Gaps and Research Opportunities

- **How clean does the air need to get for health benefits to be seen?**
- Cohort studies in Africa to document the impact of sustained air pollution exposure reduction and lung health
- Rigorous and methodologically strong studies with clear underlying behavioural theories and practices
- Evaluate early life origin of disease in relation to biomass smoke exposures in utero and early childhood
- Government-led initiatives in air quality monitoring, air quality management policies and how these impact of lung health outcomes

Behavioural change interventions to improve adherence to clean cooking

Formative research key findings

- Perceived disadvantage of solid fuel stoves
- Family influence on cooking decisions
- Heating needs
- Previous awareness and experience with LPG
- Traditional cookware and stoves used in the cooking
- Traditional foods and preferred stove for preparing them

Williams KN., et al. BMJ Open 2020;10:e037761

IMPALA International Multidisciplinary Programme to Address Lung Health & TB in Africa

FUNDED BY NIHR | National Institute for Health Research

UKaid from the British people

LSTM LIVERPOOL SCHOOL OF TROPICAL MEDICINE

Determinants of Lung Function among Infants in Uganda: a birth cohort study

IMPALA STUDY GROUP

The NIHR Global Health Research programme supports high-quality applied health research for the direct and primary benefit of people in low and middle-income countries, using UK Aid from the UK Government.

acacia

achieving control of asthma in children in africa

Children's Air Pollution Profiles in Africa

(CAPPA)

Queen Mary University of London

ACACIA study Group

FUNDED BY NIHR | National Institute for Health Research

UKaid from the British people

Conclusions

- Interventions to reduce air pollution and improve children’s lung health –mixed results
- Further research
  - Technologies-Low cost designs that are acceptable and sustainable
  - Incorporate behavioural change in studies on air pollution
  - Policies
  - Affordability, access to desired stoves/fuel, stove maintenance/ lifespan

- Consider in-depth evaluations to provide insight into fidelity, feasibility, quality of implementation and causal mechanisms

THANK YOU