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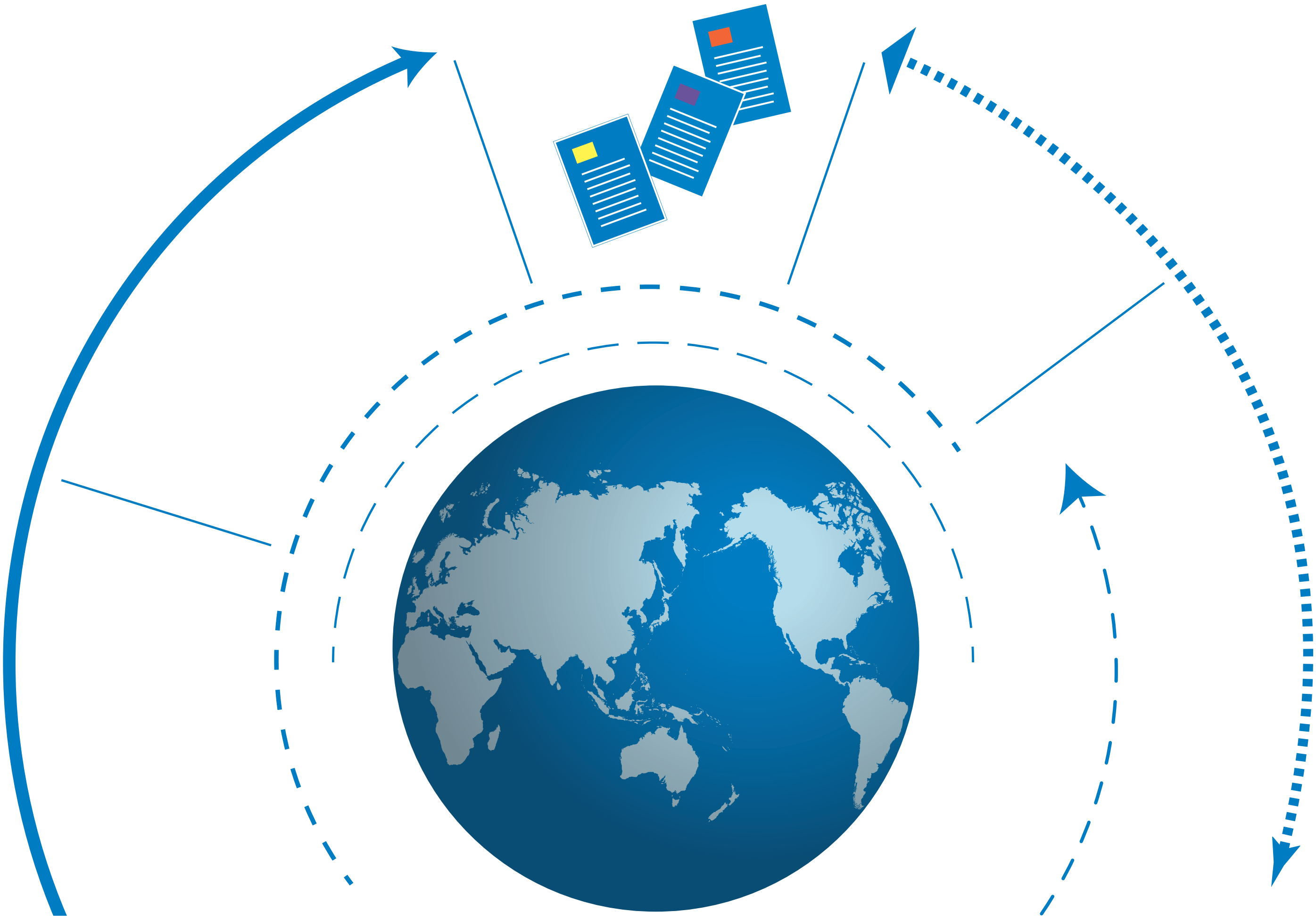
The cost of air pollution in Africa

Rana Roy



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PREFACE

Both the African Union's *Agenda 2063* and the world's *Sustainable Development Goals* (SDGs) work at reconciling industrialisation, sustainable urbanisation and public health improvements in Africa for this and future generations. This paper by Rana Roy, produced in the context of the *African Economic Outlook 2016 – Sustainable Cities and Africa's Transformation* – a joint publication by the OECD Development Centre, the African Development Bank and the United Nations Development Programme – shines new light on one of the lesser-known challenges faced by the continent in pursuit of those objectives: the rising cost of air pollution. It reaches at least three conclusions:

First, *air pollution is of significant and increasing concern for the continent*. Building on the methodology of the OECD Environment Directorate for OECD countries, China and India, the paper provides new, critical evidence on the cost of premature deaths in Africa attributable to air pollution. Between 1990 to 2013, total annual deaths from ambient particulate matter pollution (APMP, mostly caused by road transport, power generation or industry) rose by 36% to around 250 000, while deaths from household air pollution (HAP, caused by polluting forms of domestic energy use) rose by 18%, from a higher base, to well over 450 000. For Africa as a whole, Roy estimates that the economic cost of premature deaths caused by each of these sources of pollution surpasses those associated with unsafe sanitation or underweight children.

Second, *the human and economic costs of air pollution might explode without bold policy changes in Africa's urbanisation policies.* This makes it all the harder to reach regional and global sustainable development goals. Although the paper stresses the lack of precise information on the exact composition of the sources of air pollution in Africa, it does note that its deleterious impact has risen in tandem with the continent's steady and rapid urbanisation, a megatrend set to continue to unfold throughout this century. This suggests that current means of transportation and energy generation in African cities are not sustainable. Alternative models to those imported from industrialised economies, such as dependence on the individual automobile, are necessary.

Finally, *no blueprint exists for the trade-offs African policy-makers face as they strive to balance human and economic development objectives. Instead, they will have to innovate*. While OECD nations faced the challenges of economic transformation and environmental sustainability – including combatting air pollution – in a sequence, African nations are compelled to face them simultaneously. Moreover, it is striking that air pollution costs in Africa are rising in spite of slow industrialisation, and even de-industrialisation in many countries. Should this latter trend successfully be reversed, the air pollution challenge would worsen faster, unless radically new approaches and technologies were put to use. This starkly illustrates that, while the SDGs spell out universal objectives, the challenges faced by African and other developing countries in reaching them are different in nature and magnitude than those faced by industrialised economies. Policy responses will necessarily be context-specific and innovative.

These conclusions make a strong case for the Development Centre to continue refining the OECD's grasp of the distinctive challenges and opportunities faced by developing countries, and to adapt its expertise in various policy sectors to the particular needs and priorities of those countries.

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RÉSUMÉ

Ce document est une première tentative d'estimer le coût de la pollution atmosphérique en Afrique. Plus précisément : une tentative de calculer la partie la plus importante de ce « coût », à savoir le coût lié aux décès prématurés dus à la pollution de l'air. Il se fonde sur des éléments de données épidémiologiques recueillis par le « *Global Burden of Disease Study* 2013 », qui publie des résultats détaillés sur les effets de la pollution atmosphérique sur la santé – tant en termes absolus que par rapport aux autres principaux facteurs à risque –, par pays et pour l'Afrique dans son ensemble. Par ailleurs, il se fonde sur les analyses économiques développées par l'auteur, notamment les travaux récents de l'OCDE sur la « valeur d'une vie statistique », pour estimer le coût économique des effets de la pollution de l'air sur la santé. Dans la période allant de 1990 à nos jours, et à chaque intervalle quinquennal, le nombre de décès dus à la pollution atmosphérique en Afrique a augmenté au même rythme que l'accroissement de la population urbaine pendant cette même période. Le nombre de décès annuels dus à la pollution de l'air par les particules ambiantes sur le continent a augmenté de 36 % entre 1990 et 2013, à partir d'un niveau peu élevé ≈ 180 000 en 1990 à ≈ 250 000 en 2013. Au cours de cette période, les décès dus à la pollution de l'air domestique ont continué d'augmenter de 18 %, à partir d'un niveau déjà élevé de ≈ 400 000 en 1990 à plus de 450 000 en 2013. En 2013, sur le continent africain, le coût économique estimé des décès prématurés dus à la pollution de l'air par les particules ambiantes était d'environ 215 milliards de dollars. Le coût économique estimé des décès prématurés dus à la pollution de l'air domestique était d'environ 232 milliards de dollars.

Classification JEL : Q53, O55, Q51

Mots-clés : Pollution de l'air, Afrique, « valeur d'une vie statistique »

ABSTRACT

This paper is a first attempt at calculating the cost of air pollution in Africa. More precisely, it is a calculation of the major part of this cost: namely, the cost of premature deaths attributable to air pollution. It draws on the epidemiological evidence base assembled in the Global Burden of Disease Study 2013, in order to detail results for the health impacts of air pollution – in absolute terms and relative to selected other major risk factors, per country and for Africa as a whole. And it draws on the economic analyses developed by the present author, among others, in recent OECD work on the value of statistical life, in order to establish results for the economic cost of the health impacts of air pollution. In the period from 1990 to the present, and at each succeeding five-year interval in between, the death toll from air pollution in Africa has risen in tandem with the uninterrupted growth in the size of the urban population of Africa over this period. The total of annual deaths from ambient particulate matter pollution across the African continent increased by 36% from 1990 to 2013, from a then relatively low base of ≈ 180 000 in 1990 to ≈ 250 000 in 2013. Over this period, deaths from household air pollution also continued to increase, by 18%, from an already high base of ≈ 400 000 in 1990 to well over 450 000 in 2013. For Africa as a whole, as at 2013, the estimated economic cost of premature deaths from ambient particulate matter pollution was ≈ USD 215 billion. The estimated economic cost of premature deaths from household air pollution was ≈ USD 232 billion.

JEL Classification: Q53, O55, Q51

Keywords: Air pollution, Africa, Value of Statistical Life

I. INTRODUCTION

This paper is a first attempt at calculating the cost of air pollution in Africa: for each African country and for Africa as a whole. More precisely, it is a calculation of the major part of this cost: namely, the cost of premature deaths attributable to air pollution. Recent advances in epidemiological and economic research make it possible to establish the quantitative results presented here on deaths from air pollution and the cost thereof – in the Introduction and in Sections II, III and IV – with a high degree of confidence.

What cannot yet be established with the same confidence is the exact composition of the sources of air pollution in Africa. Indeed, one of the key findings reported below is that we do not possess anything like the same degree of knowledge of the sources of air pollution in African countries as we do for the countries of the OECD world. Therefore, although the available evidence on the results of air pollution is of sufficient concern to merit being brought to the immediate attention of policy-makers, the concluding discussion of the policy implications of these results, in Section V, must remain tentative.

Air pollution world-wide

Air pollution is, in the words of the World Health Organization, "the world's largest single environmental health risk" (WHO, 2014a). It is also one of the world's largest health risks *tout court*. It is a major risk factor in several diseases leading to disabilities and deaths, including cancers, lower respiratory infections, cardiovascular and cerebrovascular diseases – in short, heart disease and strokes – with the two last-named accounting for the greater share of the deaths attributable to air pollution (WHO, 2014b).

The deaths and disabilities resulting from air pollution carry a quantifiable economic cost to society.[1] As documented in recent reports (OECD, 2014; WHO Regional Office for Europe, OECD, 2015): world-wide, air pollution claims an annual toll of *several million* premature deaths and imposes thereby an annual cost of *several trillion* US dollars.

Of course, in clinical terms, individuals do not literally die from air pollution. Epidemiology distinguishes between the diseases that are diagnosed as the cause of individual deaths – for example, heart disease – and the risk factors that contribute to such

1. Unless otherwise specified, all references to "costs" in this paper refer exclusively to the "economic cost to society". In the relevant literature, this measure is also, and variously, called "social cost" or "welfare cost" or "welfare loss" or "loss in social welfare". All these terms refers to the same thing. To keep it simple, we use the term "economic cost" – or yet more simply, "cost".

diseases – for example, air pollution or tobacco smoking. With reliable data on a given population's exposure to the various risk-factors, and reliable data on exposure-response functions in the case of each risk factor, it then becomes possible to "distribute" the total of deaths from a particular disease amongst these various risk factors – that is, to attribute a given percentage of these deaths to each of the relevant risk factors. These "attributed" deaths among the population from the various risk factors as defined in epidemiology should not be confused with the diagnosed deaths of particular individuals from the various disease causes as defined in clinical practice.

But it is important to stress that this distinction does not mean that air pollution is merely a contributory factor, one among several contributory factors, in the deaths attributed to it. Rather, it is a contributory factor to a death toll *far larger* than the millions tabled below – the numbers below being the best estimates attributable to *this* particular risk factor. It follows that the technical distinction between clinically diagnosed and epidemiologically attributed deaths does not affect the absolute and relative weight of air pollution in the global death toll.

This absolute and relative weight of air pollution in the global death toll can now be estimated considerably more accurately than before, thanks to several recent technological and methodological advances. These include:

- more advanced monitoring methods, including remote-sensing technology, to estimate emissions and ambient concentrations of pollutants (see Brauer et al., 2012; Evans et al., 2012, Amann, Klimont and Wagner, 2013);

- a much-improved understanding of the relation between emissions/concentrations of pollutants and the exposure of populations thereto, and of the relation of population exposure and the health impacts thereof, resulting in the use of new integrated exposure-response functions, undergoing continuing refinement (see WHO Regional Office for Europe, 2013a,b);

- a new understanding of the link between air pollution and lung cancer (see Beelen et al., 2008; Silverman et al., 2012; Fajersztajn et al., 2013; Raaschau-Nielsen et al., 2013) – paving the way for the recent decisions by the International Agency for Research on Cancer (IARC) to classify diesel as a definite carcinogenic (IARC, 2012; Benbrahim-Tallaa et al., 2012) and outdoor air pollution as "a leading environmental cause of cancer deaths" (IARC, 2013) – and a fuller understanding of the cardiovascular, cerebrovascular and respiratory health impacts of air pollution (see Shah et al., 2013; Wellenius GA et al., 2012; Laumbach and Kipen, 2012, respectively);

- a more comprehensive and consistent methodology for assembling and analysing the epidemiological evidence, in order to establish the relative share of each relevant risk factor in deaths and disabilities for each relevant disease (see Lim, et al., 2012).

The latest epidemiological data on air pollution – as well as all other health risks – is that assembled in the Global Burden of Disease Study 2013, hereafter called GBD 2013, published in September 2015 (GBD 2013 Global Risk Factors Collaborators, 2015, and IHME, 2015). GBD 2013 provides a range of estimates, and a mid-point estimate, for each of the various individual risk factors and also for several "clusters" of risks.

Isolating the mid-point estimates reported in GBD 2013, Table 1.1 below records a total of ≈ 3 million premature deaths world-wide from each of both the two main types of air pollution, ambient particulate matter pollution (APMP) and household air pollution from solid fuels (HAP), with a smaller entry of ≈ 0.2 million for ambient ozone pollution (AOP):

Table 1.1. **Premature deaths from air pollution (in thousands), world-wide, 1990 and 2013**

	1990	2013
Ambient particulate matter pollution (APMP)	2 238	2 926
Household air pollution from solid fuels (HAP)	2 857	2 893
Ambient ozone pollution (AOP)	133	217
Air pollution risks cluster (joint effects)	4 808	5 527

Source: Extracted from IHME (2015*), Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle (http://vizhub.healthdata.org/gbd-compare/).

As recorded above in the final row of Table 1.1, GBD 2013 also provides a composite estimate for the joint effect of the various types of air pollution, with premature deaths world-wide estimated at ≈ 5.5 million. The whole is less than the sum of its parts since the effects of the individual risk factors are not fully independent of each other. As is argued *ibid.* and elsewhere (WHO 2014b; WHO Regional Office for Europe, OECD, 2015), the requisite adjustment is imprecise and estimates for joint effects need to be interpreted with caution.

Nonetheless, there is a clear message in these numbers. The estimated toll from the joint effects of air pollution, at ≈ 5.5 million premature deaths, is comparable to that from tobacco smoking, at ≈ 5.8 million (GBD 2013 Global Risk Factors Collaborators, 2015). It is now clear that air pollution is one of the main risk factors in premature deaths world-wide and deserves a health warning appropriate to the size of its impact.

Importantly, as is also recorded in Table 1.1, annual deaths from air pollution have *increased rather than decreased* over the quarter-century period from 1990: from ≈ 4.8 million in 1990 to ≈ 5.5 million at last count. The world-wide total of annual deaths from HAP has increased only marginally and is relatively little changed at ≈ 3 million. But deaths from APMP have increased significantly, from ≈ 2.2 million in 1990 to ≈ 3 million in 2013.

Deaths from AOP have increased at an even faster rate but still remain a small fraction of the total of deaths from air pollution (≈ 3% in 1990, ≈ 4% in 2013). It is the high toll from the dominant types of air pollution, HAP and APMP, that is the focus of what follows below.

Finally, it should be said that the deleterious impact of air pollution is not limited to its impact on human health. There are many other relevant impacts: on the built environment, on animal and plant health, with further consequential impacts on the productivity of agricultural and forestry resources, and on larger ecological systems. But the available evidence suggests that the calculable cost of health impacts can amount to as much as ≈ 95% of the full calculable cost – and that the cost of mortalities can amount to 90% or more of the cost of health impacts (United States EPA, 2011; OECD, 2014; WHO Regional Office for Europe, OECD, 2015). Accordingly, this paper focuses its attention on what is clearly the major part of this cost.

Air pollution in Africa

As has been documented in detail in several recent reports – and as is communicated regularly in news bulletins from Beijing and New Delhi! – the problem of air pollution in today's world is most acute in Asia, and in particular in its two major emerging economies, China and India (see *inter alia* Amann, et al., 2013, and OECD, 2014). Immersed in a process of rapid urbanisation, industrialisation and motorisation, Asia is the site of the greater share of the world's emissions of several key pollutants – and an overwhelming share of the increase in pollutant emissions since 1990. Relatedly, China and India taken together account for a disproportionate share of the total of annual deaths from APMP – an absolute majority of deaths world-wide – and an overwhelming share of the increase in that total in the recent past.

At the same time, APMP has continued to remain under intense scrutiny in the advanced economies of the OECD world, and of Western Europe and North America in particular. This is partly because these already urbanised, industrialised and motorised societies, being the first to have confronted and addressed the problem of APMP, are now possessed of an architecture of regulation and of continuous monitoring to support such regulation. And it is partly because, notwithstanding the downward trend of emissions in OECD countries over recent decades, there is now a renewed concern in these societies at the slow pace of decline in ambient concentrations of pollutants and of human exposure thereto – as evidenced in official reports and also in media commentary (see for example OECD, 2014, and WHO Regional Office for Europe, OECD, 2015, and also Vidal, 2013, and The Economist, 2015b).

Indeed, within the overall downward trend of emissions in the OECD countries, there is some evidence of reversals here and there, such as in the road transport sector, which has witnessed a rapid increase in the market share of more-polluting diesel vehicles relative to petrol vehicles (EEA, 2012; Rafaj, Amann, Siri, 2014). And road transport is the sector responsible for ≈ 50% of the deaths from APMP in the European Union, with "other transport" (aviation, maritime and rail), power generation, and "other sectors" (such as industry and agriculture) making up the remainder (OECD, 2014; WHO Regional Office for Europe, OECD, 2015).

Against this background, it is all too easy to overlook, and therefore all the more necessary to emphasise, that air pollution is also a significant – *and increasing* – problem *in Africa*.

As is reported below in Table 1.2, the total of annual deaths from APMP across the African continent increased by 36% from 1990 to 2013, from a then relatively low base of ≈ 180 000 in 1990 to ≈ 250 000 in 2013. Over this period, deaths from HAP also continued to increase, by 18%, from an already high base of ≈ 400 000 in 1990 to well over 450 000 in 2013. Thus:

Table 1.2. **Premature deaths from air pollution, Africa, 1990 and 2013**

	1990	2013
Ambient particulate matter pollution	181 291	246 403
Household air pollution from solid fuels	396 094	466 079

Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle, (http://vizhub.healthdata.org/gbd-compare/).

To be sure, this statement needs to be accompanied by several caveats.

The first and most obvious caveat is that "Africa" is not a homogenous entity and that the situation on the ground will vary from place to place. The subsequent sections detail the tally of deaths, disabilities and economic costs at a per-country level, and not simply at a continental level. But this rather obvious point need not detain the present discussion.

A second and less obvious caveat is that the information gaps in regard to air pollution in Africa, resulting from the absence of regulation and the regular monitoring that it entails, are significantly larger than is the case elsewhere (see *inter alia* Knippertz, et al., 2015, and Evans, 2015). Thus, "there are no emissions inventories for African cities … like those of London, for example, which currently have 30 m resolution" (Knippertz, et al., 2015).

A third caveat, and one which complements and compounds the second, is that, although we do not know nearly enough about air pollution in Africa, we do know that it is, in many ways, a more complex issue than is the case elsewhere. Evans (2015) puts the point starkly:

London and Lagos have entirely different air quality problems. In cities such as London, it's mainly due to the burning of hydrocarbons for transport….

> African pollution isn't like that. There is the burning of rubbish, cooking indoors with inefficient fuel stoves, millions of steel diesel electricity generators, cars which have had the catalytic converters removed and petrochemical plants, all pushing pollutants into the air over the cities…. Compounds such as sulphur dioxide, benzene and carbon monoxide that haven't been issues in Western cities for decades may be a significant problem in African cities. We simply don't know.

Finally, it remains to note that there is insufficient knowledge of the exact extent to which anthropogenic pollutant emissions are being compounded by natural process such as Saharan dust storms and forest fires to produce a worse outcome for human health in Africa than such pollutant emissions do in, say, Western Europe (Evans, 2015; Knippertz, et al., 2015).

Of course, the fact of information gaps on the sources of air pollution is an argument for continuing research to extend the evidence base – not an argument for failing to address the evidence that is already available. Nor does the contribution of nature, in the form of dust storms and forest fires and the like, absolve man of his responsibility to his own kind: it is society's responsibility to address the harm to human health resulting from anthropogenic pollutant emissions, irrespective of how, and how much, they are compounded by nature.

But the peculiarly complex character of air pollution in Africa as described in the passage cited above –the coincidence in time and place of old and new sources of air pollution, of old cars with catalytic converters removed and the latest and best of Volkswagen's output – does require pause. For it is part of a larger coincidence of old and new environmental risks, and a still larger coincidence of environmental and developmental challenges, that genuinely complicates the task of understanding and addressing the problem of air pollution in Africa.

This larger coincidence of risks is explored more fully below. But what does belong in the present summary of air pollution in Africa is this simple observation: notwithstanding the present limits of knowledge, anthropogenic air pollution is, in the main, an urban phenomenon, the result of certain patterns of urban life, of pre-regulated forms of urban production, consumption, distribution and exchange, including transport.

This is perhaps most obvious in the case of APMP. Irrespective of the extent to which the composition of the sources of APMP in African countries might differ from the pattern in those OECD countries in which road transport alone accounts for ≈ 50% of attributable deaths, it is evident that, with some exceptions such as off-shore oil facilities and agriculture, the main sources of APMP emissions, be it road transport, power generation or industry, are located, in the main, in urban environments. The same applies *mutatis mutandis* in the case of HAP, where the coincidence of high-density housing in urban areas, often in slums, and polluting forms of domestic energy use, for cooking and other consumption needs, exacerbates the health impacts of the latter.

It is therefore unsurprising to find that, in the period from 1990 to the present, and at each succeeding five-year interval in between, the death toll from air pollution in Africa has risen in tandem with the uninterrupted growth in the size of the urban population of Africa over this period – most consistently so in the case of APMP but also more or less consistently in the case of HAP. Thus:

Table 1.3. **Premature deaths from air pollution and growth in urban population, Africa, at five-year intervals from 1990 to 2010, and in 2013/2015**

	1990	1995	2000	2005	2010	2013
Household air pollution	396 094	422 895	436 463	429 199	450 969	466 079
Change over 5 years		+26 801	+13 568	–7 264	+21 770	+15 110
Rate of change		+6.8%	+03.2%	–1.7%	+5.1%	+3.4%
Ambient PM pollution	181 291	190 933	200 854	213 429	227 428	246 403
Change over 5 years		+ 9 642	+9 921	+12 575	+13 999	+ 18 975
Rate of change		+5.3%	+5.2%	+6.3%	+6.6%	+8.3%
	1990	**1995**	**2000**	**2005**	**2010**	**2015**
Total urban population (in thousands):	196 923	236 904	278 770	330 742	394 940	471 602
Change over 5 years		+39 981	+41 866	+51 972	+64 198	+76 662
Rate of change		+20.3%	+17.7%	+18.6%	+19.4%	+19.4%

Source: UN-DESA, Population Division (2014), *World Urbanization Prospects: The 2014 Revision*, CD-ROM Edition, and Table 1.3, with data extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle (http://vizhub.healthdata.org/gbd-compare/).

And if this is how the trend has asserted itself in the last quarter-century, how might it assert itself in the decades ahead?

For Africa is in the throes of an unprecedented demographic expansion. The demographic projections published by the United Nations in 2015 (UN-DESA, Population Division, 2015; see also The Economist, 2015c) show large upward revisions for population estimates in Africa – with the continent's population now expected to climb from ≈ 1.2 billion in 2015 to ≈ 2.5 billion in 2050 and thence to ≈ 4.4 billion in 2100. And the economic projections show continuing economic growth attended by continuing growth in the urban population, in both absolute and relative terms (see AfDB/OECD/UNDP (2015) and AfDB/OECD/UNDP (2016). If so, and on the assumption of *unchanged* policy settings in regard to the patterns of urban life, the future growth of urban Africa might well bring with it an explosive growth in premature deaths from the various forms of air pollution.

Better therefore to seek to understand and address the problem of air pollution as it stands today so as to forestall it worsening manifold tomorrow.

The synchronisation of challenges in present-day Africa

The epidemiological evidence base available today (see GBD 2013 *Global Risk Factors Collaborators*, 2015; IHME, 2015) – when coupled with the historical evidence on the "health transition" in the now advanced economies (see *inter alia* Costa, 2015) as well as the more recent evidence from the major emerging economies of Asia (see *inter alia* OECD, 2014) – reveals a feature of present-day Africa that does not present itself in quite the same way either in the historical record of the advanced economies or in the case of the leading emerging economies of today.

For what is observable in present-day Africa is a *synchronisation* of multiple environmental and developmental challenges, in a manner which is at odds with the more general experience of *sequential* challenges that most other societies have been able to tackle *successively rather than simultaneously*, focussing on one problem at a time – and, partly as a result, more or less successfully.

Consider the case of the first industrial economy, albeit in a highly stylized form. England succeeded in overcoming the poverty of pre-industrial society in the course of the decades following the industrial revolution of the late eighteenth century. England – in particular, the capital, London – succeeded in establishing the basic infrastructure to deliver improved water and sanitation services over the course of the second half of the nineteenth century. Thereafter, it was able to turn its attention to the problem of HAP from the burning of coal – finally cleaning up the infamous "London fog" in the mid-twentieth century. Today, it can focus on the problem of APMP, including especially from its ubiquitous motorised transport.

Mutatis mutandis, this is the path that has been taken by most societies, even if these several sequential stages have been telescoped in time in a number of cases – most dramatically so, as is shown later, in the case of China. For example, Costa's (2015) survey of the health transition, focussed on the United States but taking in several other advanced economies, highlights the protracted but profoundly consequential process of urban improvement in the major centres of the now advanced economies, whereby these cities *successively* tackled the challenges of unsafe water, unsafe sanitation, and HAP. The relevant point, however, is that this process was completed well before APMP – and, in particular, the share of APMP arising from the ubiquity of motorised transport – had become a leading factor in premature deaths.

But this is not a path available to Africa, in particular urbanising Africa, today. Here, APMP claims a rapidly increasing toll *at the same time* as the toll from HAP also continues to increase – and well before Africa has succeeded in solving the older environmental problems of unsafe water and unsafe sanitation, or indeed in solving that most characteristic feature of pre-industrial poverty, childhood undernutrition. In Africa, these risk factors are now converging, with air pollution ascending toward equality with the others as they descend.

Table 1.4 illustrates well the synchronisation of environmental and developmental challenges.

Over each five-year interval from 1990 to 2010 and thence to 2013, the total of premature deaths assigned to the risk factor "childhood underweight" has fallen steadily – but only from the high base level of ≈ 475 000 in 1990 to a still high level of ≈ 275 000 in 2013. Indeed, the larger composite risk factor of "childhood undernutrition" – encompassing "childhood underweight", "childhood wasting" and "childhood stunting" – remains the leading risk factor in 28 of 48 countries in sub-Saharan Africa, and in sub-Saharan Africa as a whole.

Deaths from the old-style environmental risk factors, "unsafe water" and "unsafe sanitation", have also fallen steadily. But once again, this is a fall from the very high levels of 1990, well over 800 000 for the former and well over 600 000 for the latter, to still high levels as at 2013, ≈ 550 000 for the former and ≈ 400 000 for the latter.

Through this period, air pollution has steadily advanced as a leading risk factor. As already noted, deaths from HAP have risen rather than fallen: from ≈ 400 000 in 1990 to well over 450 000 in 2013. And deaths from APMP have risen at an even faster rate: from ≈ 180 000 in 1990 to almost 250 000 in 2013.

The result is a *convergence* of risk factors, of the old and the new, of the pre-modern and the very modern:

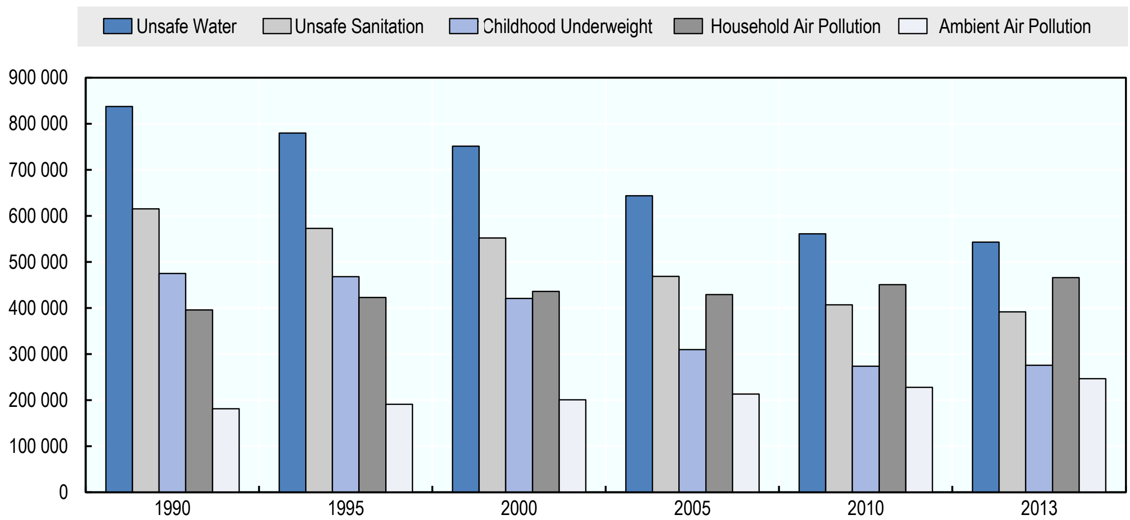
Table 1.4. **Premature deaths from selected major risk factors, Africa, at five-year intervals from 1990 to 2010, and in 2013**

	1990	1995	2000	2005	2010	2013
Unsafe water	837 702	780 095	751 892	644 136	561 342	542 855
Unsafe sanitation	615 540	573 084	551 948	468 815	407 092	391 656
Childhood underweight	474 819	467 921	420 606	309 945	273 294	275 813
Household air pollution	396 094	422 895	436 463	429 199	450 969	466 079
Ambient PM pollution	181 291	190 933	200 854	213 429	227 428	246 403

Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle (http://vizhub.healthdata.org/gbd-compare/).

Graphically presented:

Figure 1.1 (corresponding to Table 1.4). **Premature deaths from selected major risk factors, Africa, at five-year intervals from 1990 to 2010, and in 2013**



Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle (http://vizhub.healthdata.org/gbd-compare/).

There is thus a profound historical difference between London and Lagos in regard to their experience of air pollution – and not simply a difference in the manner in which the problem of air quality manifests itself in these two cities today. For there is no date in the past experience of London which exhibits such a comparable convergence and which could thus serve as a template from which Lagos could borrow. Africa cannot afford to focus on the new risk factor of APMP as if the old problem of childhood underweight, with its ≈ 275 000 deaths in 2013, had already disappeared. But neither can it afford to focus on childhood underweight as if the problem of APMP, with its ≈ 250 000 deaths, had not already appeared.

Now it is true that the contrast drawn above between present-day Africa and the historical record of England or the United States cannot be presented in the form of a table on historical deaths in these countries comparable to that of Table 1.4: the data to do so are not available. Rather, the main point at issue here – that the modern problem of APMP did not coincide at any time with the ancient problem of childhood underweight in equal measure – is deducible from a sum of different sources, including the qualitative and quantitative evidence on the health transition in the advanced economies (see *inter alia* Costa, 2015, and the sources cited therein) and the modelling of global inventories of air pollution emissions (see *inter alia* Amann, Klimont and Wagner, 2013, and the sources cited therein).

But what can be presented in sharp contrast to the pattern exhibited in present-day Africa, as captured in Table 1.4, is the evidence from China – a country that has telescoped the greater part of the developmental experience of the advanced economies in a matter of decades.

As is shown in Table 1.5 below, over the last quarter-century, and in tandem with the gathering pace of urbanisation, industrialisation and motorisation, the death toll from APMP increased uninterruptedly to reach ≈ 900 000 by 2013, and the death toll from HAP increased to a peak of ≈ 1.1 million before descending to ≈ 800 000 by 2013.

Today, China – as China well knows (see *inter alia* OECD, 2014, and the sources cited therein) – needs to confront the problem of air pollution as a matter of urgency.

But deaths from the old-style environmental risks of unsafe water and unsafe sanitation in the base year of 1990 were no higher than ≈ 150 000 and ≈ 100 000, respectively, and have been descending rapidly. And deaths from childhood underweight have descended from ≈ 50 000 in 1990 to close to zero. To put it another way: by 1990, the childhood underweight death toll in China was low enough for APMP deaths to dominate it at a ratio of *11:1*. By 2013, it had been more or less eliminated – and APMP deaths dominated it at a ratio of *671:1*.

In short, China today can focus on confronting air pollution, and as part of a larger rebalancing of its economy and society, without distraction from these older environmental and developmental challenges. Africa cannot. This is the message from Table 1.5 when contrasted to Table 1.4.

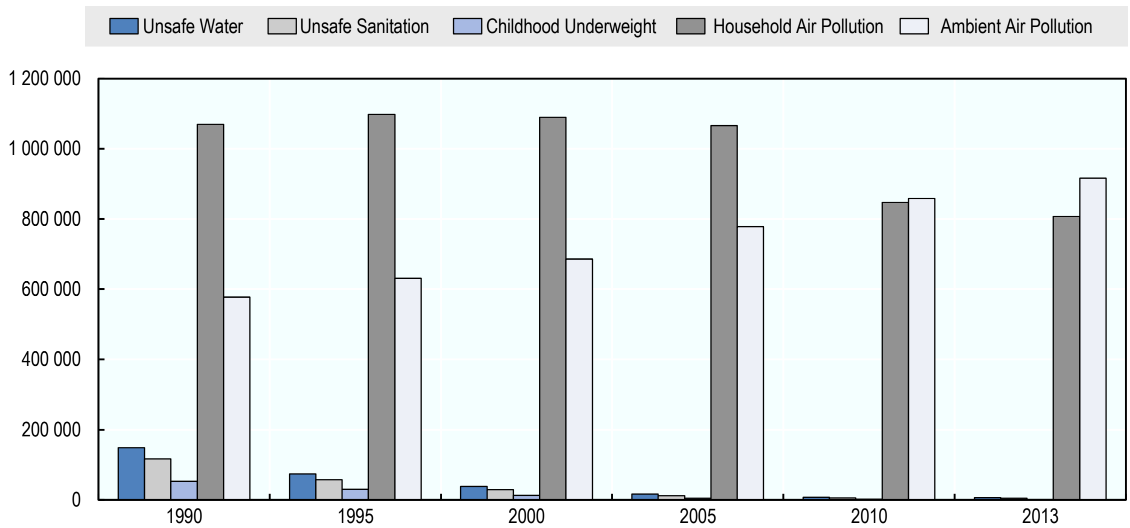
Table 1.5. **Premature deaths from selected major risk factors, China, at five-year intervals from 1990 to 2010, and in 2013**

	1990	1995	2000	2005	2010	2013
Unsafe water	148 453	74 202	38 473	16 307	7 637	6 282
Unsafe sanitation	116 991	57 880	29 684	12 252	5 381	4 233
Childhood underweight	52 616	30 007	12 509	4 381	1 788	1 366
Household air pollution	1 069 127	1 097 505	1 089 195	1 065 490	847 602	807 238
Ambient PM pollution	577 451	631 080	685 658	778 330	857 991	916 102

Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Seattle: Institute for Health Metrics and Evaluation: University of Washington (http://vizhub.healthdata.org/gbd-compare/).

Graphically presented:

Figure 1.2 (corresponding to Table 1.5). **Premature deaths from selected major risk factors, China, at five-year intervals from 1990 to 2010, and in 2013**



Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle, (http://vizhub.healthdata.org/gbd-compare/).

Africa's local air pollution as a global problem

Before turning to the detail of per-country results, there is a final generality to be noted on air pollution: it needs to be understood not simply as a local or national problem but also as a trans-national and indeed a global problem.

In the public imagination, air pollution is often viewed as a local or national issue – in contrast to the global problem of climate change. Indeed, air pollution, in the form of both HAP and APMP and even in the form of AOP, is often referred to as "local air pollution".

This view is inaccurate on several grounds.

It is true that the impacts of air pollution fall, *in the main*, on those within a defined radius of the sources of the relevant emissions. Nonetheless, the radius is not sensitive to national boundaries: recent European research has established well enough that the health impact of air pollution in any given member state of the European Union is, in part, a function of the emissions generated in another (see *inter alia* Yim, Barret, 2012; WHO Regional Office for Europe, OECD, 2015). Nor are these trans-boundary impacts always a minor share of the total. As The Economist (2015b) observes:

> "Air pollution is not a local issue: around a third of Britain's dirty air is swept over from the continent."

Mutatis mutandis, the same basic finding in European research in regard to the fact of trans-national impacts in the case of the countries of the European Union will apply in the case of the countries of the African continent.

Moreover, "local" air pollution is also a contributor to the "global" problem of climate change. If CO_2 emissions are the primary contributor to the latter, it is as well to remember that, in the words of The Economist (2015a),

> "carbon dioxide is not, however, the only greenhouse pollutant. Methane, black carbon (i.e., soot) and hydrofluorocarbons also warm the world a good deal."

And black carbon is *inter alia* a product of "open wood fires" – that is, a key component part of Africa's HAP emissions – and of "the exhaust pipes of unsophisticated diesel vehicles" – that is, a key component part of Africa's APMP emissions.

More specifically, recent research (Knippertz, et al. 2015) suggests that increasing anthropogenic emissions in West Africa – resulting from the "domestic, traffic and industrial pollutants" attending the expansion of cities such as Lagos but also from "the rapid development of the oil industry along the Guinea coast" – may be impacting on the climate, in particular the West African monsoon, to a greater extent than previously estimated.

In short, Africa's local air pollution is not simply a local issue. African countries have a mutual interest in mitigating air pollution in their neighbouring countries. And the world at large, including the OECD world, has an interest in mitigating air pollution in Africa. How that interest is best translated into action is a matter that is best left for the conclusion.

II. THE HEALTH IMPACTS OF AIR POLLUTION RELATIVE TO OTHER MAJOR RISK FACTORS

Section II details the available evidence on the health impacts of air pollution, in absolute terms and relative to selected other major risk factors, per country and for Africa as a whole, as at 2013, and as established in GBD 2013.

The epidemiological estimates reported below are, as before, for five selected major risk factors. These are, first, the immediate focus of the analysis: the two main types of air pollution, “ambient particulate matter pollution” (APMP) and “household air pollution from solid fuels” (HAP). And then, in order to locate air pollution within the larger pattern of synchronisation sketched earlier, three older environmental and development challenges: “unsafe water”, “unsafe sanitation”, and “childhood underweight.”

The reporting of these epidemiological estimates encompasses three key indicators: premature deaths; YLLs, or years of life lost; DALYs, or disability-adjusted life years lost. The first two tables below concern deaths only: Table 2.1 the deaths from APMP and HAP, and Table 2.2 the deaths from all five selected risk factors. Thereafter, 2.3-5 report for all three indicators, for APMP and HAP, then unsafe water and sanitation, and finally childhood underweight.

In the main, the per-country results are in conformity with the broad pattern of the global results established in recent reports (OECD, 2014; WHO Regional Office for Europe, OECD, 2015) and of the continent-wide results summarised above in Section I.

As noted earlier (Section I, Table 1.1): on a global scale, premature deaths from APMP and HAP respectively now stand roughly at a ratio of 1:1. In the world’s highest income economies, deaths from HAP are now at near-zero levels (and often no longer monitored). In Africa, however, deaths from HAP outnumber deaths from APMP at a ratio of almost 2:1.

As shown in Table 2.1 below, deaths from HAP are now at low levels only in the relatively higher-income countries of North Africa – and one or two small high-income countries elsewhere. Across most of sub-Saharan Africa, deaths from HAP remain at high levels, and continue to outnumber deaths from APMP, often at ratios of well above 2:1. Equally, it is the relatively higher-income countries of North Africa, including especially Egypt with its densely populated Cairo, which exhibit proportionately higher levels of deaths from APMP.

Compare and contrast in this regard the three most populous countries in Africa. Egypt, with a population slightly below that of Ethiopia and roughly half that of Nigeria, exhibits a toll from APMP, at ≈ 36 000, which is roughly twice that of Ethiopia, at ≈ 20 000, and roughly equal to that of Nigeria, at ≈ 40 000.

Now it is true that the high-income countries of North Africa, with their disproportionately higher levels of deaths from APMP, are also the countries that are likely to be the ones most impacted by one of the main non-anthropogenic sources of air pollution, namely, Saharan dust. To the extent that they are – an extent that cannot yet be determined – the absolute levels of APMP deaths will be higher than otherwise.

Nonetheless, the correlation between income levels and the relative burden of the two types of air pollution is clearly apparent. It is only a few high-income countries amongst the 54 detailed below – Algeria, Egypt, Libya, Mauritius, Morocco, Seychelles, Tunisia – that have driven down deaths from HAP to the point where *they can afford to view the problem of air pollution as the problem of the present and future course of APMP alone*. Most African countries are obliged rather to confront present and future APMP without having first solved the problem of HAP. Ethiopia's death toll from APMP relative to HAP stands at a ratio of 0.35:1, Nigeria's at 0.6:1, and South Africa is still more or less at convergence.

Table 2.1. **Premature deaths from air pollution, per country, Africa, 2013**

	Ambient PM pollution	Household air pollution
Algeria	7 230	309
Angola	4 223	11 002
Benin	2 284	4 726
Botswana	124	274
Burkina Faso	3 900	7 688
Burundi	2 078	5 926
Cabo Verde	163	126
Cameroon	5 690	12 172
CAR	1 603	3 989
Chad	4 176	8 104
Comoros	22	370
Congo	1 003	2 606
DRC	18 929	48 937
Côte d'Ivoire	5628	12 134
Djibouti	268	105
Egypt	35 805	257
Equatorial Guinea	131	502
Eritrea	1 334	2 210
Ethiopia	19 993	57 591
Gabon	407	460
Gambia	462	887
Ghana	6 707	12 633
Guinea	3 537	7 710

Table 2.1. **Premature deaths from air pollution, per country, Africa, 2013 (cont.)**

	Ambient PM pollution	Household air pollution
Guinea-Bissau	683	1 374
Kenya	3 952	15 440
Lesotho	467	1 261
Liberia	967	2 325
Libya	1 824	78
Madagascar	502	18 385
Malawi	1 590	9 092
Mali	5 269	10 484
Mauritania	1 405	1 468
Mauritius	315	46
Morocco	6 014	953
Mozambique	1 117	11 750
Namibia	204	910
Niger	5 326	9 934
Nigeria	39 825	67 148
Rwanda	1 812	5 188
Sao Tome and Principe	5	92
Senegal	3 651	4 942
Seychelles	3	2
Sierra Leone	1 785	4 068
Somalia	1 239	7 775
South Africa	10 432	9 587
South Sudan	2 799	8 043
Sudan	10 973	18 498
Swaziland	236	722
Tanzania	3 845	22 729
Togo	1 431	3 125
Tunisia	3 468	121
Uganda	5 933	16 630
Zambia	2 120	7 003
Zimbabwe	1 508	6 191
Total	**246 397**	**466 082**

Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle, (http://vizhub.healthdata.org/gbd-compare/).

To be sure, it could be argued that the coincidence of deaths from the two main types of air pollution is not unique to Africa. Something similar is observable, and has been observed, in the case of other emerging economies – for example, in parts of Eastern Europe to the east of the European Union (see *inter alia* WHO Regional Office for Europe, OECD, 2015), in China to some extent (see above, Table 1.4), in the less advanced among the rapidly emerging economies in Asia, the India-s as distinct from the China-s (see *inter alia* OECD, 2014), and so on. Across the world, it is perhaps *only* the high-income countries that can afford to view the problem of air pollution as the problem of the present and future course of APMP alone.

But what is shown below in Table 2.2 is, if not unique to Africa, a distinctive feature of its current state of development. That is: the extent of convergence in the toll of deaths from *all* these selected risk factors – of APPM with HAP, of both types of air pollution with unsafe water and sanitation, of each of the environmental risk factors with childhood underweight.

As reported earlier in Table 1.3: in 1990, for Africa as a whole, the total of premature deaths from the then highest of these risk factors, unsafe water, stood at ≈ 840 000. That is: a ratio of ≈ 4.6:1, relative to the then lowest, APMP, at ≈ 180 000. By 2013, the ratio of deaths from unsafe water, still the highest at ≈ 550 000, to deaths from APMP, still the lowest at ≈ 250 000, had fallen to 2.2:1.

And as shown below in Table 2.2, this broad pattern of convergence holds true for the great majority of the individual African countries. Only a few of the 54 countries – as before, including Algeria, Egypt, Libya, Mauritius, Morocco, Seychelles, Tunisia – can be said to have broken free of it, having pushed down the toll from childhood underweight, as well as the toll from HAP and unsafe sanitation if not yet unsafe water, to proportionately low levels.

Once more, a comparison of the most populous countries is instructive.

- In relatively high-income Egypt, the ratio of the toll from the highest of the risk factors, APMP, to the lowest, HAP, stands at > 100:1, with each of HAP, unsafe sanitation and childhood underweight having been pushed down to low levels.

- In contrast: in relatively middle-income Nigeria, by far the most populous country in Africa and in income terms the more representative, the ratio of the highest, HAP, to the lowest, APMP, stands at no more than ≈ 1.7:1. In short, *all* five selected risk factors are in play in roughly equal measure.

- In considerably lower-income Ethiopia, the relevant ratio, once again HAP to APMP, is at ≈ 3:1. Even in the Democratic Republic of Congo, one of Africa's poorest countries, the relevant ratio, unsafe water to APMP, is at no more than ≈ 4.4:1.

- Remarkably, not even relatively high-income South Africa is as yet fully free of this pattern. For although the toll from childhood underweight is at a relatively low level, it is still high enough to ensure that the ratio of the highest to the lowest, in this case unsafe water to childhood underweight, is no more than ≈ 8.3:1.

In short, what was observed earlier in relation to the continent as a whole also applies to most of its individual countries: Africa cannot afford to focus on the new environmental risk factor of APMP as if the older environmental risks, or the ancient curse of under-development as represented here by childhood underweight, had already disappeared; neither can it afford to focus on these older problems as if the new problem of APMP had not already appeared.

Table 2.2. **Premature deaths from selected major risk factors, per country, Africa, 2013**

	Ambient PM pollution	Household air pollution	Unsafe water	Unsafe sanitation	Childhood underweight
Algeria	7 230	309	1 874	457	371
Angola	4 223	11 002	14 156	8 948	6 619
Benin	2 284	4 726	3 222	2 453	1 583
Botswana	124	274	439	287	50
Burkina Faso	3 900	7 688	12 097	9 215	4 488
Burundi	2 078	5 926	6 860	5 198	3 661
Cabo Verde	163	126	45	26	9
Cameroon	5 690	12 172	10 565	7 635	5 701
CAR	1 603	3 989	4 740	3 614	2 296
Chad	4 176	8 104	21 033	16 141	9 474
Comoros	22	370	302	231	73
Congo	1 003	2 606	1 458	1 077	620
DRC	18 929	48 937	83 245	62 538	45 279
Côte d'Ivoire	5628	12 134	9 688	6 818	4 991
Djibouti	268	105	307	205	117
Egypt	35 805	257	5 283	296	319
Equatorial Guinea	131	502	196	27	144
Eritrea	1 334	2 210	4 554	3 401	1 620
Ethiopia	19 993	57 591	54 473	42 015	20 040
Gabon	407	460	416	269	144
Gambia	462	887	645	422	336
Ghana	6 707	12 633	4 484	3 081	5 379
Guinea	3 537	7 710	5 259	3 848	3 679
Guinea-Bissau	683	1 374	1 238	893	676
Kenya	3 952	15 440	25 066	18 670	7 012
Lesotho	467	1 261	1 998	1 517	260
Liberia	967	2 325	2 098	1 498	897
Libya	1 824	78	160	12	4
Madagascar	502	18 385	11 593	9 157	6 350
Malawi	1 590	9 092	14 094	10 978	5 340
Mali	5 269	10 484	17 800	13 428	10 358
Mauritania	1 405	1 468	1 621	1 150	519
Mauritius	315	46	33	3	1
Morocco	6 014	953	1 421	489	147
Mozambique	1 117	11 750	12 300	9 392	3 517
Namibia	204	910	861	511	100
Niger	5 326	9 934	21 500	16 596	12 276
Nigeria	39 825	67 148	59 440	40 786	61 746
Rwanda	1 812	5 188	3 596	2 711	1 864
Sao Tome and Principe	5	92	30	19	13
Senegal	3 651	4 942	5 738	3 719	2 087
Seychelles	3	2	3	1	0
Sierra Leone	1 785	4 068	2 467	1 831	2 448

Table 2.2. **Premature deaths from selected major risk factors, per country, Africa, 2013 (cont.)**

	Ambient PM pollution	Household air pollution	Unsafe water	Unsafe sanitation	Childhood underweight
Somalia	1 239	7 775	17 573	12 407	5 422
South Africa	10 432	9 587	14 170	6 237	1 707
South Sudan	2 799	8 043	12 136	9 268	5 245
Sudan	10 973	18 498	9 207	7 140	2 112
Swaziland	236	722	799	541	123
Tanzania	3 845	22 729	23 919	18 384	10 813
Togo	1 431	3 125	3 101	2 255	1 603
Tunisia	3 468	121	265	51	4
Uganda	5 933	16 630	14 861	11 168	8 786
Zambia	2 120	7 003	8 705	6 220	5 186
Zimbabwe	1 508	6 191	9 723	6 423	2 204
Total	**246 397**	**466 082**	**542 857**	**391 657**	**275 813**

Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle, (http://vizhub.healthdata.org/gbd-compare/).

As noted earlier, the reporting of the epidemiological estimates in this section is intended to encompass three key indicators:

- premature deaths;
- YLLs, or years of life lost;
- and DALYs, or disability-adjusted life years lost.

And subtracting YLLs from DALYs yields a fourth key indicator:

- YLDs, or years of life lost to disability.

For most fatal diseases and their risk factors, YLDs tend to be, always and everywhere, a small fraction of DALYs. As shown below in Table 2.3: in the case of APMP, YLDs are a *very* small fraction of DALYs in all the countries of Africa, amounting to ≈ 1% of DALYs for Africa as a whole. And as is shown in Tables 2.3-2.5: YLDs are a small fraction of DALYs in the case of *all* five selected risk factors, the percentage share ranging from ≈ 1% to ≈ 5% of DALYs for Africa as a whole.

In Africa, more so than elsewhere, deaths dominate disabilities and the years of life lost to death, YLLs, dominate the years of life lost to disability, YLDs.

This is unsurprising. As is explained elsewhere in the recent literature (see WHO Regional Office for Europe, OECD, 2015):

"YLDs expressed as a percentage of DALYs reflect not only the prevalence of illness in a given country but also that country's ability to respond to illness by treating individuals and prolonging their lives."

Thus, it is precisely the world's high-income countries, and especially those high-income countries with the highest standards of health care provision, that record the highest share of YLDs. For example, in the case of the 50+ countries of the WHO European Region, YLDs from APMP amount to ≈ 5% of DALYs across the Region but are as high as ≈ 13% in the case of Israel and Switzerland (WHO Regional Office for Europe, OECD, 2015).

There is one more result that needs to be noted here in the trio of tables below: YLLs considered as a multiple of deaths.

As a multiple of deaths, YLLs are, and obviously, highest in the case of childhood underweight (as reported in Table 2.5): the years lost in this case amount to a full life-span. But they are also higher for unsafe water and unsafe sanitation (Table 2.4) than for either category of air pollution (Table 2.3). And they are, if slightly, higher for HAP than for APMP.

And this serves to reinforce the argument advanced in Section I: notwithstanding the deserved focus in the present study on the rising death toll from air pollution and in particular the rapidly rising toll from APMP, it is nonetheless necessary to remain mindful of the full spectrum of environmental and developmental challenges in present-day Africa.

Table 2.3. **Premature deaths/ YLLs/DALYs from air pollution, per country, Africa, 2013**

	Ambient PM pollution			Household air pollution		
	Deaths	YLLs	DALYs	Deaths	YLLs	DALYs
Algeria	7 230	170 497	174 266	309	7 153	8 211
Angola	4 223	191 470	192 742	11 002	494 367	510 908
Benin	2 284	82 123	83 371	4 726	167 847	177 041
Botswana	124	4 062	4 146	274	8 801	10 143
Burkina Faso	3 900	209 874	211 906	7 688	417 321	432 157
Burundi	2 078	85 341	86 193	5 926	246 880	255 836
Cabo Verde	163	3 450	3 579	126	2 577	2 896
Cameroon	5 690	249 102	251 269	12 172	529 597	547 953
CAR	1 603	67 213	67 705	3 989	163 757	168 469
Chad	4 176	250 039	251 548	8 104	483 958	493 820
Comoros	22	696	700	370	12 178	12 888
Congo	1 003	32 921	33 206	2 606	83 580	87 524
DRC	18 929	901 779	907 520	48 937	2 294 918	2 355 573
Côte d'Ivoire	5628	245953	247 968	12 134	528 385	546 950
Djibouti	268	8 343	8 491	105	3 279	3 519
Egypt	35 805	910 640	926 636	257	6 054	6 619
Equatorial Guinea	131	5605	5 644	502	21 336	22 168
Eritrea	1 334	50 344	51 288	2 210	83 933	89 133

Table 2.3. **Premature deaths/ YLLs/DALYs from air pollution, per country, Africa, 2013 (cont.)**

	Ambient PM pollution			Household air pollution		
	Deaths	YLLs	Deaths	YLLs	Deaths	YLLs
Ethiopia	19 993	724 340	732 325	57 591	2 131 775	2 235 069
Gabon	407	11 425	11 523	460	12 618	13 288
Gambia	462	20 654	20 906	887	39 207	40 623
Ghana	6 707	218 231	221 955	12 633	406 493	432 575
Guinea	3 537	158 353	159 950	7 710	340 944	353 546
Guinea-Bissau	683	29 140	29 390	1 374	58 288	60 064
Kenya	3 952	172 715	174 540	15 440	686 257	725 579
Lesotho	467	17 067	17 185	1 261	45 257	47 255
Liberia	967	38 046	38 503	2 325	91 403	95 792
Libya	1 824	41 535	42 505	78	1 741	1 944
Madagascar	502	17 002	17 076	18 385	630 161	655 465
Malawi	1 590	77 071	77 478	9 092	455 500	470 785
Mali	5 269	276 950	279 220	10 484	539 345	553 837
Mauritania	1 405	52 530	53 712	1 468	53 852	56 994
Mauritius	315	6 822	6 928	46	988	1 106
Morocco	6 014	152 376	155 997	953	23 671	27 177
Mozambique	1 117	43 601	43 932	11 750	474 940	501 666
Namibia	204	5 966	6 023	910	26 136	28 216
Niger	5 326	289 081	291 848	9 934	535 067	551 054
Nigeria	39 825	2 044 354	2 066 697	67 148	3 438 222	3 574 158
Rwanda	1 812	71 430	72 321	5 188	206 888	217 370
Sao Tome and Principe	5	150	151	92	2 592	2 763
Senegal	3 651	126 199	128 686	4 942	167 663	178 378
Seychelles	3	55	56	2	31	35
Sierra Leone	1 785	88 568	89 276	4 068	201 324	207 156
Somalia	1 239	61 794	62 134	7 775	396 475	406 962
South Africa	10 432	242 668	248 608	9 587	217 115	245 332
South Sudan	2 799	123 858	124 779	8 043	359 971	374 686
Sudan	10 973	336 866	340 685	18 498	552 348	590 906
Swaziland	236	8 993	9 056	722	27 041	28 180
Tanzania	3 845	172 509	173 832	22 729	1 053 072	1 101 115
Togo	1 431	65 327	66 204	3 125	141 758	148 524
Tunisia	3 468	70 730	71 951	121	2 349	2 638
Uganda	5 933	257 064	259 973	16 630	729 482	759 267
Zambia	2 120	87 482	88 065	7 003	297 321	307 721
Zimbabwe	1 508	57 362	57 756	6 191	236 738	248 704
Total	**246 397**	**9 637 766**	**9 749 404**	**466 082**	**20 139 954**	**20 977 738**

Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle, (http://vizhub.healthdata.org/gbd-compare/).

Table 2.4. **Premature deaths/YLLs/DALYs from unsafe water/sanitation, per country, Africa, 2013**

	Unsafe water			Unsafe sanitation		
	Deaths	YLLs	DALYs	Deaths	YLLs	DALYs
Algeria	1 874	105 350	155 387	457	25 702	37 874
Angola	14 156	968 430	1 023 313	8 948	612 201	646 883
Benin	3 222	18 9105	202 627	2 453	143 930	154 216
Botswana	439	26 638	28 698	287	17 394	18 739
Burkina Faso	12 097	864 375	895 843	9 215	658 466	682 430
Burundi	6 860	417 984	438 984	5 198	316 616	332 554
Cabo Verde	45	2 874	3 364	26	1 684	1 971
Cameroon	10 565	727 193	769 656	7 635	525559	556 235
CAR	4 740	287376	297 244	3 614	219 096	226 613
Chad	21 033	1 555 813	1 585 699	16 141	1 193 916	1 216 840
Comoros	302	13 527	14 642	231	10 346	11 198
Congo	1 458	75 243	84 281	1 077	55 595	62 267
DRC	83 245	5 616 485	5 778 609	62 538	4 219 928	4 341 529
Côte d’Ivoire	9 688	653 095	693 237	6 818	459 660	487 893
Djibouti	307	15 284	15 549	205	10 212	10 389
Egypt	5 283	381 900	478 387	296	21 369	26 767
Equatorial Guinea	196	12 462	13 703	27	1 707	1 877
Eritrea	4 554	239 997	249 351	3 401	179 188	186 176
Ethiopia	54 473	2 867 988	2 998 900	42 015	2 212 190	2 313 108
Gabon	416	19 434	22 721	269	12 582	14 708
Gambia	645	49 948	53 756	422	32 667	35 159
Ghana	4 484	289 869	313 361	3 081	199 156	215 290
Guinea	5 259	320 940	338 215	3 848	234 838	247 482
Guinea-Bissau	1 238	86 206	89 410	893	62 173	64 484
Kenya	25 066	1 407 923	1 465 051	18 670	1 048 938	1 091 453
Lesotho	1 998	121 644	123 815	1 517	92 348	93 995
Liberia	2 098	135 059	143 561	1 498	96 398	102 465
Libya	160	9 669	16 988	12	733	1 286
Madagascar	11 593	719 232	749 612	9 157	568 081	592 058
Malawi	14 094	891 093	920 315	10 978	694 140	716 875
Mali	17 800	1 331 572	1 361 251	13 428	1 004 437	1 026 815
Mauritania	1 621	97 568	104 124	1 150	69 235	73 893
Mauritius	33	1 319	1 530	3	129	150
Morocco	1 421	85 173	124 861	489	29 331	42 994
Mozambique	12 300	672 267	705 148	9 392	513 417	538 501
Namibia	861	44 599	47 111	511	26 451	27 941
Niger	21 500	1 579 213	1 632 000	16 596	1 219 055	1 259 755
Nigeria	59 440	4 352 382	4 569 223	40 786	2 986 878	3 135 609
Rwanda	3 596	214 441	233 469	2 711	161 728	176 086
Sao Tome and Principe	30	1 933	2 237	19	1 276	1 477
Senegal	5 738	373 477	402 481	3 719	242 039	260 844
Seychelles	3	123	141	1	27	31

Table 2.4. **Premature deaths/YLLs/DALYs from unsafe water/sanitation, per country, Africa, 2013 (cont.)**

	Unsafe water			Unsafe sanitation		
	Deaths	YLLs	Deaths	YLLs	Deaths	YLLs
Sierra Leone	2 467	177 104	185 981	1 831	131 482	138 068
Somalia	17 573	1 050 466	1 066 270	12 407	741 296	752 454
South Africa	14 170	725 818	772 991	6 237	319 274	340 053
South Sudan	12 136	721 131	736 804	9 268	550 652	562 618
Sudan	9 207	685 535	756 423	7 140	531 644	586 548
Swaziland	799	54 661	56 107	541	37 007	37 985
Tanzania	23 919	1 312 916	1 383 186	18 384	1 009 415	1 063 379
Togo	3 101	221 005	238 744	2 255	160 755	173 649
Tunisia	265	14 301	26 900	51	2 733	5 137
Uganda	14 861	969 375	1 044 406	11 168	728 608	784 997
Zambia	8 705	543 263	568 099	6 220	388 181	405 923
Zimbabwe	9 723	678 529	697 010	6 423	448 251	460 466
Total	**542 857**	**34 980 307**	**36 680 776**	**391 657**	**25 230 114**	**26 346 187**

Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle, (http://vizhub.healthdata.org/gbd-compare/).

Table 2.5. **Premature deaths/YLLs/DALYs from childhood underweight, per country, Africa, 2013**

	Childhood underweight		
	Deaths	YLLs	DALYs
Algeria	371	31 808	43 779
Angola	6 619	564 113	581 927
Benin	1 583	134 985	144 040
Botswana	50	4 299	5 065
Burkina Faso	4 488	382 546	407 672
Burundi	3 661	311 827	321 416
Cabo Verde	9	733	868
Cameroon	5 701	485 311	498 770
CAR	2 296	195 778	201 183
Chad	9 474	806 346	827 326
Comoros	73	6 218	6 858
Congo	620	52 989	56 209
DRC	45 279	3 859 853	3 952 707
Côte d'Ivoire	4 991	425 872	443 002
Djibouti	117	9 978	11 064
Egypt	319	27 344	55 427
Equatorial Guinea	144	12 253	12 399
Eritrea	1 620	137 882	147 416
Ethiopia	20 040	1 708 319	1 794 749
Gabon	144	12 303	12 806

Table 2.5. **Premature deaths/YLLs/DALYs from childhood underweight, per country, Africa, 2013 (cont.)**

	Childhood underweight		
	Deaths	Deaths	Deaths
Gambia	336	28 627	30 457
Ghana	5 379	457 779	472 501
Guinea	3 679	313 357	323 960
Guinea-Bissau	676	57 551	58 780
Kenya	7 012	598 283	627 174
Lesotho	260	22 200	22 779
Liberia	897	76 681	79 743
Libya	4	361	2 076
Madagascar	6 350	541 384	581 201
Malawi	5 340	454 468	461 515
Mali	10 358	880 466	908 156
Mauritania	519	44 148	47 663
Mauritius	1	120	471
Morocco	147	12 554	24 426
Mozambique	3 517	299 795	314 421
Namibia	100	8 490	9 726
Niger	12 276	1 043 633	1 076 222
Nigeria	61 746	5 252 780	5 489 197
Rwanda	1 864	159 016	163 328
Sao Tome and Principe	13	1 132	1 280
Senegal	2 087	177 637	191 125
Seychelles	0	0	7
Sierra Leone	2 448	208 954	214 987
Somalia	5 422	461 911	478 904
South Africa	1 707	145 810	159 565
South Sudan	5 245	446 861	466 347
Sudan	2 112	180 302	236 325
Swaziland	123	10 507	10 650
Tanzania	10 813	922 747	945 357
Togo	1 603	136 447	142 491
Tunisia	4	358	1 888
Uganda	8 786	749 382	770 699
Zambia	5 186	442 203	450 500
Zimbabwe	2 204	187 636	191 771
Total	**275 813**	**23 494 337**	**24 480 375**

Source: Extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level (on line data base – Viz Hub –GBD Compare), Institute for Health Metrics and Evaluation, University of Washington, Seattle, (http://vizhub.healthdata.org/gbd-compare/).

III. CALCULATING THE COST OF HEALTH IMPACTS: THE VALUE OF STATISTICAL LIFE

As a bridge to translating the quantified health impacts reported in Section II into quantifiable economic costs in Section IV, Section III summaries the methodology adopted here for this translation.

Present-day economics possesses a standard method by which to measure the cost of mortalities at the level of society as a whole: the "value of statistical life" (VSL), as derived from aggregating individuals' willingness to pay (WTP) to secure a marginal reduction in the risk of premature death.[2]

The algebraic reasoning informing this method is elegant in its simplicity. Suppose that each individual has an expected utility function, EU, relating the utility of consumption over a given period, U(y), and the risk of dying in that period, r, of the form:

$$\mathbf{EU(y, r) = (1 - r)\, U(y).}$$

The individual's WTP, to maintain the same expected utility in the event of a reduction in the level of risk from r to r′ is the solution to the equation:

$$\mathbf{EU(y - WTP, r') = EU(y, r).}$$

VSL is thus the marginal rate of substitution between these two valued items, consumption and the reduction in the risk of dying, such that:

$$\mathbf{VSL = \delta WTP/\delta r.}$$

Now the simplest way to discover the relevant individuals' WTP is – of course – to ask them. A WTP survey is thus the starting point of the calculation. OECD (2012) describes the basic process of deriving a VSL value from such a survey:

> The survey finds an average WTP of USD 30 for a reduction in the annual risk of dying from air pollution from 3 in 100 000 to 2 in 100 000. This means that each individual is willing to pay USD 30 to have this 1 in 100 000 reduction in risk. In this example, for every 100 000 people, one death would be prevented with this risk

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2. For recent expositions on the subject, including various its complexities, see *inter alia* Biausque (2012); Braathen (2012); Hunt, Ferguson (2010); Hunt (2011); OECD (2012); OECD (2014); WHO Regional Office for Europe, OECD (2015). The exposition here borrows heavily from the present author's previous exposition in OECD (2014) and WHO Regional Office for Europe, OECD (2015).

reduction. Summing the individual WTP values of USD 30 over 100 000 people gives the VSL value – USD 3 million in this case. It is important to emphasise that the VSL is not the value of an identified person's life, but rather an aggregation of individual values for small changes in risk of death (OECD, 2012).

And this turn yields a simple result permitting us to assess the impact of a given problem and of proposals to mitigate it. The economic cost of the impact being studied becomes the VSL value multiplied by the number of premature deaths. The economic benefit of a mitigating action becomes the same VSL value multiplied by the number of lives saved.

Moreover, thanks to the multiyear research effort embodied in OECD (2012) – including its meta-analysis of VSLs starting with I 095 values from 92 published studies – researchers and policy-makers now possess a set of OECD-recommended values for average adult VSL. In units of 2005 United States dollars (USD), the recommended range for OECD countries is USD 1.5 million– 4.5 million, the recommended base value is USD 3 million.

This in turn enables the computation of country-specific VSL values countries both within and outside the OECD and for years beyond 2005 – and, with it, the opportunity for informed decision-making on major risk factors in a timely manner, without needing to conduct expensive, large-scale surveys in every location and on every occasion.

Now it may be objected that the use of *country-specific* VSL values necessarily reproduces the existing income inequalities between countries: the cost of 100 deaths in a high-income country becomes higher than the cost of 100 deaths in a low-income country. But this is to misunderstand the context and purpose of the exercise.

As argued above, a VSL value is an aggregation of individual valuations: an aggregation of individuals' WTP, as communicated through WTP surveys, to secure a marginal reduction in the risk of premature death. But individuals are differentially endowed with the means with which to make such a trade-off. At one end of the scale, some are obliged to work for their living for a dollar a day; at the other, some hold an inherited fortune, yielding an unearned income of a billion dollars per year. All societies have therefore sought to "socialise" these risks to a greater or lesser extent in the form of public goods: to share the burden of these risks at least partially through the collective treasury rather than impose it exclusively on the individual's purse at the point of need. And it so happens that the level at which this socialization of risks is executed today is, principally, the level of the nation-state.

The point here is not that the problem of air pollution for example is, in the nature of things, exclusively national: as already noted, it is not. Rather, the point is that the burden of addressing the problem and bearing the costs of any solution – that is, effecting the sacrifice of some value in consumption to secure the greater value of lives saved – is, in the present day, principally the responsibility of national governments.

This result is not a normative judgement on the part of economists. It is simply an act of recognition of present-day reality: the citizens of any given lower-income country are, in the main, obliged to execute their relevant trade-offs largely without reference to the resources of other, higher-income countries.

It is therefore appropriate to *commence* the task of quantifying the problem by means of using country-specific VSL values – without forgetting to note that international transfers to reflect international responsibilities may well be needed to *complete* the task of solving the problem.

There is however an important amendment to the formula used in previous OECD work that is required in the present exercise.

The OECD formula in its last published incarnations (OECD, 2014) includes these features *inter alia*:

- the OECD base value of USD 3 million in year 2005 is the starting point for the calculation of VSL values both for OECD countries and for other countries;
- the calculation is in purchasing power parity (PPP)-adjusted USD estimates of per-capita GDP in each country relative to the OECD block's per capita GDP;
- the income elasticity beta applied is 0.8, being the mid-point of the best estimate of 0.7-0.9 established in OECD research;
- the income elasticity adjustment is applied not only to the 2005 level but also to its real growth in the post-2005 period.

The result for any given country, C, for any given year, here 2013, is thus as follows:

$$\mathbf{VSL\ C_{2013} = VSL\ OECD_{2005}\ x\ (Y\ C_{2005}/Y\ OECD_{2005})^{\beta}\ x\ (1 + \%\Delta P + \%\Delta Y)^{\beta}.}$$

The assumption of an income elasticity of 0.8 means this: as incomes rise, the willingness to pay for a marginal reduction in the risk of death from a given risk also rises – but not quite in proportion to the rise in incomes. This assumption is empirically well-grounded in the case of the advanced economies – as is the resulting estimate of 0.8 (OECD, 2012; OECD, 2014).

However, as was argued in an important recent paper (Hammit, Robinson, 2011) and is also noted in current World Bank research (Narain, Sall, 2016), there are reasons to suppose that this assumption does not necessarily hold true for emerging economies. A step-change in life circumstances away from deep poverty alters the "willingness to pay" more sharply than does a gradual but modest rise in incomes in the already high-income countries. There is therefore a case for adopting the more common assumption in the development literature of an income elasticity of 1. Indeed, there is also a case for assuming an income elasticity of > 1.

Table 3.1 below presents computed country-specific VSL values for each African country under three different scenarios for income elasticity: the OECD assumption of 0.8, the development literature assumption of 1 and a further option assuming an elasticity of 1.2.

It is proposed here to adopt the assumption of an income elasticity of 1. This means that the resulting VSL values and consequent economic cost estimates for African countries today will start from a lower base than would be the case under the assumption of 0.8 – but also that these values and estimates will rise more rapidly over time, a feature that will show itself in *future* studies of the problem in the rapidly emerging economies of Africa.

Table 3.1. **Computed country-specific VSL values under different scenarios for income elasticity, Africa, 2013**

	OECD (2014) formula with income elasticity beta of 0.8	OECD (2014) formula but with income elasticity beta of 1	OECD (2014) formula but with income elasticity beta of 1.2
	USD millions	*USD millions*	*USD millions*
Algeria	1.951	1.752	1.573
Angola	1.751	1.531	1.338
Benin	0.383	0.229	0.137
Botswana	2.698	2.627	2.558
Burkina Faso	0.337	0.195	0.113
Burundi	0.289	0.161	0.090
Cabo Verde	0.999	0.759	0.577
Cameroon	0.522	0.337	0.218
CAR	0.176	0.087	0.043
Chad	0.438	0.271	0.167
Comoros	0.320	0.183	0.105
Congo	0.999	0.759	0.576
DRC	0.278	0.153	0.084
Côte d'Ivoire	0.578	0.383	0.254
Djibouti	0.580	0.384	0.255
Egypt	2.130	1.955	1.794
Equatorial Guinea	4.568	5.074	5.636
Ethiopia	0.524	0.339	0.219
Gabon	2.272	2.120	1.977
Gambia	0.372	0.221	0.131
Ghana	0.991	0.751	0.569
Guinea	0.693	0.481	0.333
Guinea-Bissau	0.309	0.175	0.099
Kenya	0.792	0.568	0.407
Lesotho	0.540	0.352	0.229
Liberia	0.249	0.134	0.072
Libya	3.310	3.392	3.477
Madagascar	0.458	0.286	0.179
Malawi	0.272	0.149	0.082
Mali	0.353	0.207	0.121
Mauritania	0.754	0.534	0.378
Mauritius	2.521	2.413	2.311
Morocco	1.024	0.782	0.598
Mozambique	0.303	0.171	0.096
Namibia	1.570	1.335	1.135
Niger	0.212	0.110	0.057
Nigeria	1.295	1.049	0.851
Rwanda	0.366	0.216	0.128
Sao Tome and Principe	1.102	0.858	0.668
Senegal	0.426	0.261	0.160
Seychelles	3.908	4.176	4.461
South Africa	2.047	1.860	1.691
Sudan	1.121	0.876	0.685
Swaziland	1.225	0.980	0.783

Table 3.1. Computed country-specific VSL values under different scenarios for income elasticity, Africa, 2013 (cont.)

	OECD (2014) formula with income elasticity beta of 0.8	OECD (2014) formula but with income elasticity beta of 1	OECD (2014) formula but with income elasticity beta of 1.2
	USD millions	*USD millions*	*USD millions*
Tanzania	0.619	0.417	0.281
Togo	0.307	0.174	0.098
Tunisia	1.606	1.374	1.175
Uganda	0.468	0.294	0.185
Zambia	0.908	0.673	0.499

Note 1: All computations with the OECD base value of USD 3 million in 2005, adjusted for differences in per capita GDP, and adjusted for post-2005 income growth and inflation.

Note 2: Insufficient data available to complete calculations for the following countries: Eritrea, Sierra Leone, Somalia and Zimbabwe.

Note 3: Equatorial Guinea is an outrider here and this particular VSL estimate should not be taken at face value. It is one of the few countries in the world where, in consequence of temporary resource revenues, the current level of per capita GDP is a very poor indicator of real household incomes – and, in reality, it is the latter which informs the "willingness to pay". As a general rule, however, per capita GDP at PPP rates remains a good enough indicator.

Source: Extracted from World Bank (2015), *World Development Indicators* (online database), Washington, DC. http://databank.worldbank.org/data/reports.aspx?Code=FP.CPI.TOTL.ZG&id=af3ce82b&report_name=Popular_indicators&populartype=series&ispopular=y#.

A final point on methodology is this. As has been argued at length elsewhere (OECD, 2014; WHO Regional Office for Europe, OECD, 2015), whereas economics possesses a standard method by which to measure the cost of mortalities, it does not yet possess a standard method by which to measure the cost of morbidities. Nor do researchers and policymakers possess anything like a set of OECD-recommended values for the several and various morbidities. The issue is being addressed, step by step, in current OECD research (see Hunt, et al, 2016); but it is yet to be solved.

Nonetheless, for the advanced economies, in particular the United States and the European Union, the available evidence from recent comprehensive studies of the costs of air pollution (United States EPA, 2011; European Commission, 2013; Holland, 2014) suggests that mortality costs amount to ≈ 92% of the cost of health impacts, with morbidity costs amounting to ≈ 8% (see the analysis in WHO Regional Office for Europe, OECD, 2015).

Given this background, the procedure adopted in recent work by the OECD and the WHO (OECD, 2014; WHO Regional Office for Europe, OECD, 2015) has been to "add on" a round figure of 10% to the calculated cost of mortalities, as derived from VSL values, so as to arrive at an indicative estimate of the overall cost of the health impacts of air pollution – meaning that morbidities are assumed here to account for ≈ 9%, or < 10%, of the total cost of health impacts from air pollution, with mortalities accounting for ≈ 91%, or > 90%, of the total.

But this is not a procedure that can be applied to the calculation of costs in Africa. First, there is too little empirical research in the case of the African countries to support the choice of *any* particular estimate for the "add on" component. Moreover, as is clear from Tables 2.3-5, YLLs make up an overwhelming share of DALYs in the case of all the selected risk factors. And in the case of APMP, YLDs amount only to ≈ 1% of DALYs for Africa as a whole.

Given this evidence, little is lost by the procedure of stopping at the cost of mortalities, to the exclusion of morbidities, in calculating the cost of the health impacts of air pollution in Africa.

IV. THE COST OF AIR POLLUTION RELATIVE TO OTHER MAJOR RISK FACTORS

Section IV reports on the economic cost of the health impacts of air pollution, in absolute terms and relative to selected other major risk factors, per country and for Africa as a whole, as at 2013.

As noted above at the end of Section III, the cost calculation is for the cost of deaths only. There is insufficient research to support any particular estimate for the economic cost of disabilities; at the same time, the small share of years lost to disability, within the total of disability-adjusted life years lost, suggests that little is lost by limiting the cost calculation to the cost of deaths only.

Nonetheless, it is obvious that the economic cost of disabilities cannot be zero. Therefore, it follows that the cost calculations reported below in Table 4.1 and Table 4.2 are less than the full cost of the health impacts of air pollution and each of the other selected risk factors.

Considering first the calculations for the two main types of air pollution reported in Table 4.1:

- For Africa as a whole, as at 2013, the estimated economic cost of premature deaths from APMP is ≈ USD 215 billion. The estimated economic cost of premature deaths from HAP is ≈ USD 232 billion. Taken together, the resulting estimated cost of premature deaths from air pollution in Africa, at USD ≈ 450 billion, is, clearly, large.
- There is a greater convergence in the results for these two types of air pollution in the economic cost calculation than in the epidemiological calculation. This is because of the relatively higher prevalence of APMP in the relatively higher-income countries of the continent, with consequently higher VSL values.
- In terms of its economic cost as well as in terms of its epidemiological toll, the "new" problem of APMP is too large to be ignored or deferred to tomorrow's agenda. At the same time, Africa cannot afford to ignore the "old" problem of HAP or to consider it largely solved: it is only a few high-income countries – Algeria, Egypt, Libya, Mauritius, Morocco, Seychelles, and Tunisia – that can afford to view the problem of air pollution as being a problem of APMP alone.

Considering the calculations for the spectrum of selected risk factors reported in Table 4.2:

- For Africa as a whole, as at 2013, the estimated economic cost of premature deaths from all four selected environmental risk factors, APMP, HAP, unsafe water and unsafe sanitation, is > USD 850 billion. The cost is large – too large to be ignored.

- There is a greater convergence in the results for all the selected risk factors in the economic cost calculation than in the epidemiological calculation. Once more, this is because of the relatively higher prevalence of APMP in the relatively higher-income countries of the continent. As was reported earlier (in Section I, Table 1.4, and Section II, Table 2.2): in epidemiological terms, APMP still claims the lowest, albeit the most rapidly rising, toll amongst these risk factors. But as is reported below, its economic cost already outstrips that of unsafe sanitation and childhood underweight.
- As before, it remains true – indeed, it is true *a fortiori* – that it is only a few countries in Africa that can afford to focus on APMP alone amongst these selected risk factors. And it is only in one country, Tunisia, that the cost of APMP trumps the cost of each of the other selected risk factors by a multiple of more than 10.

Table 4.1. **Economic cost of premature deaths from air pollution, per country, Africa, 2013**

	Ambient PM pollution	Household air pollution
	USD millions	*USD millions*
Algeria	12 667	541
Angola	6 465	16 844
Benin	522	1 081
Botswana	326	720
Burkina Faso	762	1 501
Burundi	335	956
Cabo Verde	124	96
Cameroon	1 919	4 104
CAR	139	347
Chad	1 130	2 192
Comoros	4	68
Congo	761	1 977
DRC	2 898	7 491
Côte d'Ivoire	2 157	4 651
Djibouti	103	40
Egypt	69 986	502
Equatorial Guinea	665	2 547
Ethiopia	6 770	19 502
Gabon	863	975
Gambia	102	196
Ghana	5 037	9 488
Guinea	1 700	3 706
Guinea-Bissau	120	241
Kenya	2 244	8 766
Lesotho	164	444
Liberia	130	311
Libya	6 188	265
Madagascar	144	5 257
Malawi	238	1 358
Mali	1 091	2 171
Mauritania	751	784
Mauritius	760	111
Morocco	4 705	746

Table 4.1. Economic cost of premature deaths from air pollution, per country, Africa, 2013 (cont.)

	Ambient PM pollution	Household air pollution
	USD millions	*USD millions*
Mozambique	191	2 006
Namibia	272	1 215
Niger	584	1 088
Nigeria	41 796	70 471
Rwanda	392	1 123
Sao Tome and Principe	4	79
Senegal	954	1 292
Seychelles	13	8
South Africa	19 406	17 834
Sudan	9 613	16 206
Swaziland	231	707
Tanzania	1 603	9 477
Togo	248	542
Tunisia	4 765	166
Uganda	1 744	4 888
Zambia	1 428	4 716
Total (of countries with available data)	**215 212**	**231 798**

Notes: All computations with the OECD base value of USD 3 million in 2005, adjusted for differences in per capita GDP with an income elasticity of 1, and adjusted for post-2005 income growth and inflation. Insufficient data available to complete calculations for the following countries: Eritrea, Sierra Leone, Somalia and Zimbabwe.

Source: Table 2.1, with data extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level [on line data base – Viz Hub –GBD Compare], Institute for Health Metrics and Evaluation: University of Washington, Seattle, (http://vizhub.healthdata.org/gbd-compare/), and Table 3.1, with data extracted from World Bank (2015), *World Development Indicators* (online database), Washington, DC. http://databank.worldbank.org/data/reports.aspx?Code=FP.CPI.TOTL.ZG&id=af3ce82b&report_name=Popular_indicators&populartype=series&ispopular=y#.

Table 4.2. Economic cost of premature deaths from selected major risk factors, per country, Africa, 2013

	Ambient PM pollution	Household air pollution	Unsafe water	Unsafe sanitation	Childhood underweight
	USD millions	*USD millions*	*USD millions*	*USD millions*	*USD millions*
Algeria	12 667	541	3 283	801	650
Angola	6 465	16 844	21 673	13 699	10 134
Benin	522	1 081	737	561	362
Botswana	326	720	1 153	754	131
Burkina Faso	762	1 501	2 362	1 799	876
Burundi	335	956	1 107	838	591
Cabo Verde	124	96	34	20	7
Cameroon	1 919	4 104	3 562	2 574	1 922
CAR	139	347	412	314	200
Chad	1 130	2 192	5 690	4 367	2 563
Comoros	4	68	55	42	13
Congo	761	1 977	1 106	817	470
DRC	2 898	7 491	12 743	9 573	6 931

Table 4.2. **Economic cost of premature deaths from selected major risk factors, per country, Africa, 2013 (cont.)**

	Ambient PM pollution	Household air pollution	Unsafe water	Unsafe sanitation	Childhood underweight
	USD millions	*USD millions*	*USD millions*	*USD millions*	*USD millions*
Côte d'Ivoire	2 157	4 651	3 713	2 613	1 913
Djibouti	103	40	118	79	45
Egypt	69 986	502	10 326	579	624
Equatorial Guinea	665	2 547	995	137	731
Ethiopia	6 770	19 502	18 446	14 228	6 786
Gabon	863	975	882	570	305
Gambia	102	196	142	93	74
Ghana	5 037	9 488	3 368	2 314	4 040
Guinea	1 700	3 706	2 528	1 850	1 769
Guinea-Bissau	120	241	217	156	118
Kenya	2 244	8 766	14 230	10 599	3 981
Lesotho	164	444	703	534	92
Liberia	130	311	281	201	120
Libya	6 188	265	543	41	14
Madagascar	144	5 257	3 315	2 618	1 816
Malawi	238	1 358	2 106	1 640	798
Mali	1 091	2 171	3 686	2 781	2 145
Mauritania	751	784	866	614	277
Mauritius	760	111	80	7	2
Morocco	4 705	746	1 112	383	115
Mozambique	191	2 006	2 100	1 603	600
Namibia	272	1 215	1 149	682	133
Niger	584	1 088	2 356	1 818	1 345
Nigeria	41 796	70 471	62 382	42 805	64 802
Rwanda	392	1 123	778	587	404
Sao Tome and Principe	4	79	26	16	11
Senegal	954	1 292	1 500	972	546
Seychelles	13	8	13	4	0
South Africa	19 406	17 834	26 359	11 602	3 175
Sudan	9 613	16 206	8 066	6 255	1 850
Swaziland	231	707	783	530	121
Tanzania	1 603	9 477	9 973	7 665	4 508
Togo	248	542	538	391	278
Tunisia	4 765	166	364	70	5
Uganda	1 744	4 888	4 368	3 283	2 583
Zambia	1 428	4 716	5 862	4 189	3 492
Total (of countries with available data)	**215 212**	**231 798**	**248 191**	**160 670**	**134 468**

Notes: All computations with the OECD base value of USD 3 million in 2005, adjusted for differences in per capita GDP with an income elasticity of 1, and adjusted for post-2005 income growth and inflation. Insufficient data available to complete calculations for the following countries: Eritrea, Sierra Leone, Somalia and Zimbabwe.

Source: Table 2.1, with data extracted from IHME (2015), *Global Burden of Disease Study 2013* (GBD 2013) – Results by Risk Factor – Country Level [on line data base – Viz Hub –GBD Compare], Institute for Health Metrics and Evaluation, University of Washington (http://vizhub.healthdata.org/gbd-compare/), and Table 3.1, with data extracted from World Bank (2015), *World Development Indicators* (online database), Washington, DC.
http://databank.worldbank.org/data/reports.aspx?Code=FP.CPI.TOTL.ZG&id=af3ce82b&report_name=Popular_indicators&populartype=series&ispopular=y#

V. CONCLUSION: SOME IMPLICATIONS FOR POLICY

As noted in the opening section, one of the key findings reported in this paper is that we do not possess anything like the same degree of knowledge of the sources of air pollution in African countries as we do for the countries of the OECD world. This is not a *pro forma* disclaimer, let alone a statement of false modesty. The point is essential: without a more exact knowledge of the sources and pathways of air pollution in Africa, it is not possible to recommend with confidence a definite set of policies to address the problem – except perhaps to recommend the gathering of the requisite knowledge as a matter of priority.

It follows that the discussion below is necessarily tentative, a first step toward a dialogue on the implications for policy, and not at all a finished document of policy advice.

The cost of air pollution and the case for action

If all other things were equal, the evidence presented in the preceding section on the cost of air pollution would constitute *ipso facto* the best part of a clear-cut case for immediate action.

The calculation of the economic cost of premature deaths is, after all, intended to serve as an input to decision-making: quantifying the impact of a given problem in this manner enables decision-makers to assess, by means of cost-benefit analysis (CBA), the utility of proposals to mitigate the problem. Thus, the economic cost of the impact being studied becomes the VSL value multiplied by the number of premature deaths. The economic benefit of a mitigating action becomes the same VSL value multiplied by the number of lives saved. And this anticipated benefit, when compared to the cost of the proposed mitigation and found to be in excess of the latter, becomes the rationale for proceeding with the mitigation.[3]

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3. To put it more formally and more precisely (see for example Roy, 2008, and OECD, 2014), the optimal investment rule can be stated as follows: proceed with the investment if, and only if, it offers a positive net present value at the chosen discount rate, such that the present value of its discounted future streams of benefits exceeds the present value of its discounted future streams of costs:

$$NPV = PV_b - PV_c = b_0 - c_0 + \frac{b_1 - c_1}{(1+r)} + \frac{b_2 - c_2}{(1+r)^2} + \ldots + \frac{b_n - c_n}{(1+r)^n} > 0$$

where NPV is net present value, PV_b is the present value of benefits, PV_c is the present value of costs, r is the discount rate, and n is the final year of evaluation.

And what the evidence presented above shows is that air pollution in Africa claims a large and increasing toll and, with it, a large and increasing cost: as at 2013, ≈ USD 215 billion in the case of APMP and ≈ USD 232 billion in the case of HAP.

In principle, therefore, it would suffice to show that there are mitigation measures available to reduce air pollution at a cost less than the benefits they would secure, by way of a reduction in deaths from air pollution, in order to make the case for enacting these measures.

And there is indeed abundant evidence from the recent experience of the advanced economies that there are several tried-and-tested mitigation measures to reduce air pollution which cost only a small fraction of the benefits that they are capable of securing.

Thus, for example, the mitigation measures in the United States Clean Air Act Amendments of 1990 were estimated in *ex post* evaluation to have delivered a benefit-cost ratio (BCR) of *31:1* (see United States EPA, 2011, and WHO Regional Office for Europe, OECD, 2015); and the mitigation measures in the European Union's recently proposed Clean Air Package were estimated in *ex-ante* evaluation to yield a BCR of *42:1* (see European Commission, 2013, Holland, 2014, and WHO Regional Office for Europe, OECD, 2015).

But all other things are not equal in several respects.

Critically, as reported in Section I, there is as yet insufficient knowledge of the sources and pathways of air pollution and its impacts across much of Africa – and yet sufficient knowledge to know that the answer is likely to be a highly complex mix, inclusive of a contribution from non-anthropogenic sources. This complicates the task of selecting targeted mitigation measures and decisions to implement such measures.

For example: given an identified source of pollution and a set of potential technical solutions, one would need to know whether that source is indeed making any more than a marginal contribution to pollution driven by a natural factor such as Saharan dust – and if so, how and by how much – in order to take an informed decision on which, if any, of the potential technical solutions is worth the cost in fiscal resources.

Moreover, as was also argued in Section I and is evidenced in the tables of the succeeding sections, Africa today is experiencing a synchronisation of environmental and developmental challenges – a convergence of several leading risk factors, of APMP with HAP, of both types of air pollution with unsafe water and sanitation, of each of the environmental risk factors with childhood underweight, and so on – which is at variance with the experience of the advanced economies and of the more advanced of the emerging economies. This complicates the task of prioritising the problems to be addressed even before one begins the task of selecting the measures with which to address them.

Thus, most African countries are not in the position of a China, which can today focus on air pollution undistracted by problems such as unsafe water or unsafe sanitation or childhood underweight – let alone in the position of a Switzerland, which can focus on APPM undistracted by the problem of HAP or any other of these old-style problems.

None of this is an argument for *inaction* on air pollution in Africa. But it is an argument for prioritising research to complete the evidence base needed for informed decision-making – beginning with establishing inventories of pollutant emissions, differentiated in sufficient detail. And it is an argument for exploring the scope for action with due caution – mindful of the limits of our current knowledge, of the complexity of the task, and of the larger context within which the problem of air pollution is situated.

That said, and with due caution, it is now perhaps possible to offer some remarks on the potential scope for focussed action on APMP as well as on the potential scope for synchronised action on multiple old and new environmental risks.

The scope for focussed action on APMP

In the advanced economies of Western Europe and North America, the problem of air pollution is more or less reducible to that of APMP: deaths and disabilities from HAP are now at near-zero levels (WHO Regional Office for Europe, OECD, 2015). And the problem of APMP in these economies is now *largely* reducible to emissions from the road transport sector. This sector is the *leading* cause of air pollution-related deaths – both in the European Union, where there is good evidence to suggest that its share of responsibility is ≈ 50% (Yim, Barrett, 2012; OECD, 2014; WHO Regional Office for Europe, OECD, 2015), and in the United States, where the available suggests that its share is < 50% but larger than that of any other single sector (Caiazzo et al., 2013; Dedoussi, 2014; WHO Regional Office for Europe, OECD, 2015).

In turn, this dominant causal role of the road transport sector permits decision-makers in these economies to focus, if they so choose, on what is by now a well-researched suite of mitigation measures appropriate to this sector (see *inter alia* Roy, 2008; OECD, 2014; WHO Regional Office for Europe, OECD, 2015).

Clearly, the above does not hold true generally in the case of Africa. And yet: here, too, there may indeed be some scope for focussed action on specifically transport-related APMP, even if this scope needs to be defined with some care.

As noted earlier, it is only in a few relatively high-income countries, predominantly in North Africa – Algeria, Egypt, Libya, Mauritius, Morocco, Seychelles, and Tunisia – that the problem of air pollution is largely reducible to that of APMP alone. But here at least mitigating action on air pollution can be made largely reducible to action focussed on APMP. The challenge here is rather one of identifying the extent of the anthropogenic contribution to APMP in order to determine the appropriate extent of human action to mitigate it.

And although there is as yet insufficient evidence to define either the sectoral share of road transport or the specific pathways by which it transmits the problem (for example, old cars with catalytic converters removed as against brand-new diesel-engine cars), it is very likely the case that road transport has a non-trivial share in APMP – especially in these relatively high-income North African countries with already high levels of motorisation.

This does not *per se* establish the case for borrowing freely from the suite of measures applicable to the advanced economies: even ahead of completing the evidence base, it is safe to say that the BCRs obtainable from such measures in the advanced economies will not generally be available in Africa, even in its highest-income countries.

Nonetheless, there is at least at one well-researched policy measure already on the policy agenda of many African governments, mainly as a result of its implications for government revenues, which could well provide the co-benefit of being an effective mitigation measure for transport-related APMP across Africa: namely, the reform of fuel subsidies.

Research by the international agencies – including especially by the International Monetary Fund (IMF) and reported in IMF and related literature (see especially Coady et al., 2015, but also Arze del Granado et al., 2010, Alleyne et al., 2014, Whitley, van der Burg, 2015) – has established a wealth of evidence to show that, on a world scale and to a greater or lesser extent in every region of the world including in Africa, the explicit and implicit government subsidies for the production and consumption of energy (including coal, petroleum, natural gas, electricity) are large; that these subsidies result in large losses in welfare; and that their removal would result in large gains in welfare.[4]

Of particular relevance to the present discussion are the below findings on the net gain in welfare ("the benefits from reduced environmental damage and higher revenue minus the losses from consumers facing higher energy prices") that would follow from a removal of energy subsidies:

- For the world as a whole as well as in most of its regions, the greater part of the net gain in welfare follows from the removal of subsidies for coal. But both in sub-Saharan Africa and in the larger region of which North Africa is a part (MENAP: Middle East, North Africa, Afghanistan and Pakistan), a very large part of the welfare gain is a result of the removal of subsidies for petroleum. It is close to 50% of the welfare gain in the case of sub-Saharan Africa and well over 80% in the case of MENAP (Coady et al., 2015, Figure 12).

4. The work embodied in this literature, including the latest IMF Working Paper from May 2015 (Coady et al., 2015), predates the latest findings from the two studies that constitute much of the evidence base for the present paper: the WHO-OECD study (by the present author) published in April 2015 and the GBD 2013 Study published in September 2015. Moreover, this is work-in-progress and its definitions and methodologies are not entirely free of controversy. Therefore, and notwithstanding the critically important findings to date in the IMF literature, this paper has avoided reference to the absolute numbers in this literature. But the ratios and the narratives they support are not in conflict with those advanced in this paper.

- A critical component of the welfare gain is the reduction of deaths from air pollution. Both in sub-Saharan Africa and in MENAP, the removal of energy subsidies leads to a > 50% reduction in deaths from air pollution. In sub-Saharan Africa, the removal of subsidies for petroleum accounts for ≈ 20% of this result; here, coal is still the biggest factor. In MENAP, the removal of subsidies for petroleum accounts for ≈ 80% of the reduction in deaths from air pollution (Coady et al., 2015, Figure 11).

Therefore, and whether the potential gain is a ≈ 10% reduction in deaths from air pollution or a ≈ 40% reduction, accelerating the reform of subsidies for petroleum, with the ultimate aim of removing them altogether, *may* provide a singular focus for action on transport-related APMP across Africa – even if the argument applies *a fortiori* in North Africa.[5]

In any event, assuming that the reform of fuel subsidies will indeed proceed, and proceed independently of any findings in the present paper, this process of reform *will* provide an important opportunity for both *ex-ante* and *ex-post* research on the extent to which any reduction of subsidies for petroleum serves to mitigate transport-related APMP.

And – of course – the same opportunity for research, and hence the basis for informing future action on APMP, applies in the case of all other fuels and sectors impacted by this process of subsidy reform: in particular, coal, which figures prominently in several sub-Saharan countries, and electricity, which figures to a greater or lesser extent everywhere.

Beyond this, certain individual countries may find themselves well-placed to go further.

For example, North African countries with high levels of motorisation *may* be able to borrow more freely from the tool-kit of transport-related mitigation measures available to the advanced economies (Roy, 2008; OECD, 2014; WHO Regional Office for Europe, OECD, 2015). South Africa, which will surely be reviewing its experience of limited road-user pricing, might also wish to review the findings of recent OECD research (Harding, 2014; Roy, 2014) detailing the extent of subsidy for company-car usage, and the extent of its contribution to air pollution, in OECD member- and partner-countries: given that the extent of the subsidy in South Africa is very close to the OECD average (Harding, 2014), this particular OECD-recommended reform *may* prove to be of immediate relevance here. And so on.

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5. Although the issue of distributional equity lies outside the scope of the present inquiry, it will not hurt to note that current fuel subsidies tend to be regressive in their distributional impact. As reported in Whitley and van der Burg (2015):

> "Consumer subsidies are often justified as a way to help the poorest households or to provide access to energy. There is however increasing evidence that fossil fuel subsidies are in fact regressive, since their benefits accrue mainly to wealthier social sectors or to large fossil fuel companies, while their costs are borne by the whole population.… An IMF review [the reference here is to Arze del Granado et al., 2010] of consumer subsidies in developing countries, with similar findings for SSA [sub-Saharan Africa], found that only 7% of the benefits reached the poorest 20% of income groups, and that subsidies for petrol and diesel most benefited the rich…"

But then, a full exploration of the scope for action in individual African countries lies well beyond the limits of the present study.

A final point needs to be noted in regard to action on APMP. At present, we do not know its sectoral sources in Africa – though it is safe to guess that road transport today does not figure anywhere near as prominently in Africa as it does in the advanced economies of the OECD world where motorisation is ubiquitous. And it may be that research in the years immediately ahead will find that it is of relatively limited *immediate* importance. Nonetheless, the *future* impact of road transport in Africa – and of potential mitigating actions in relation to it – needs to be factored into any serious thinking on APMP.

For Africa today is home to a mere 3% of the world's vehicle population (AfDB/OECD/UNDP (2016)) – even as it is home to 16% of the world's human population (United Nations, Department of Economic and Social Affairs, Population Division, 2015). In today's Africa, 30-35% of residents still get to work by foot (AfDB/OECD/UNDP (2016). But this is most unlikely to hold true in tomorrow's Africa – even as its population continues to climb, both absolutely and as a share of the world's population. Therefore, in Africa as elsewhere, addressing the issue of road transport in one way or another will be, at some point, an essential part of addressing the problem of APMP.

The scope for synchronised action on multiple risks

If the evidence presented in this paper suffices to establish that APMP in Africa is a significant and increasing problem, it also serves to situate it in a more complex context. Here, APMP itself has many and varied sources other than modern forms of motorisation. HAP is still the more significant problem across Africa and its toll is still increasing. The old environmental risk factors of unsafe water and unsafe sanitation still claim a high if declining toll. And even the ancient curse of childhood undernutrition is yet to be lifted.

In this context, it is evident that the remarks offered above in regard to APMP – the need to prioritise research, beginning with establishing inventories of pollutant emissions; the potential for effecting pollution mitigation as a co-benefit of policies to reform fuel subsidies; the research opportunity provided by this reform process to ascertain the extent of its capacity to mitigate pollution; the need to keep the road transport sector in clear sight in any long-term perspective to address the problem – can offer no more than a partial answer.

The question then becomes whether, in the face of the larger synchronisation of environmental challenges, there is also scope for an appropriately synchronised response.

As it happens, *all* the environmental risk factors discussed above do properly belong together in a newly emerging policy agenda: what may be called the urban policy agenda.

As explored elsewhere in the African Economic Outlook 2016, the African continent is currently in the throes of an "urban transition". This involves an enormous expansion of its urban population in absolute terms. It also involves an expansion of the share of the urban population within its total population – that is, "urbanisation" in the strict sense. The emerging question for urban policy-makers therefore is not only or mainly what to do about current conditions in existing cities and towns and as experienced by their current residents but, rather, whether to accommodate the new populations within these existing cities and towns and in these current conditions or, in the alternative, whether and how to plan this expansion so as to secure the "urban dividend" that characterises the historical experience of the now urbanised advanced economies.

In the same vein, the emerging question for environmental policy-makers is not only or mainly what to do about the current state of the several various environmental risk factors but whether to accommodate an enormous expansion of the numbers of people using *current* modes of transport, of household cooking, of rubbish disposal, of water and sanitation services, and so on, or, in the alternative, whether and how to plan and provide *new* modes of urban living that would change the relevant functions of all these environmental risk factors.

As argued earlier, the now advanced economies were able to tackle these several and various environmental challenges more or less sequentially – and only after the conquest of pre-industrial poverty and well before the challenge of APMP had appeared in its modern forms. But there is no mystery to how these challenges were overcome: massive public investment in urban improvements. As Costa (2015) notes in regard to water:

Clean water technologies and other public health expenditures that made the dramatic mortality declines in cities possible were expensive. The value of the mean big city water system in 1915 was close to USD 300 million in 2003 US dollars…. Chicago's water system was valued at USD 1 027 million in 2003 US dollars.

And the same point applies to past investments in all manner of urban improvements: in modern sanitation, in connecting natural gas pipes so as to replace polluting forms of household cooking, and so on.

Nor is there any serious doubt about the abiding result of these investments: healthier, more productive workers, living and working in healthier, more productive cities (see Costa, 2015).

To be sure, investments in urban improvements alone would not automatically change environmental outcomes for those outside the urban areas – for Africa's still numerous rural populations – nor would it automatically change the outcome of risk factors such as childhood underweight and other such indicators of pre-industrial poverty. But quite apart from the enormous change they would make to environmental outcomes for the ever-expanding urban population, the wealth provided by the urban dividend would make it considerably easier to tackle all such outstanding problems more effectively.

In principle, therefore, there is indeed clear scope for a synchronised mitigation of Africa's multiple environmental risks: it lies in a comprehensive programme of public investment in urban improvements, simultaneously tackling water, sanitation, HAP and elements of APMP across a wide front, and as part of a comprehensive urban policy agenda.

It scarcely needs to be said that the difficulty of the task should not be minimised: a comprehensive programme of public investment in urban improvements would be expensive, and might well appear at first sight to be forbiddingly expensive.

But if the numbers tabled in this paper are any guide – if the cost of the four selected environmental risk factors crossed USD 850 billion in 2013 and is now on track to cross USD 1 trillion in the near future if it has not done so already – then there is at least a case to undertake the CBAs required to arrive at an informed answer to the question.

Moreover, there is one important advantage to this broad-based approach. APMP in its more sophisticated modern form (air and maritime traffic, new cars and new power plants) is a problem that is yet to be fully solved anywhere. But all the advanced economies and many emerging economies around the world have indeed solved the old-style environmental problems of unsafe water and unsafe sanitation, of most forms of HAP, and of the most unsophisticated forms of APMP (the old, defective vehicles, the do-it-yourself diesel generators, and so on). That is, they have reduced to zero, or near-zero, the sum of premature deaths from these risks (GBD 2013 Global Risk Factors Collaborators, 2015; IHME, 2015). Neither the science nor the sum of techniques, processes and products required to solve all this is unknown. It has been done before elsewhere. It could be done tomorrow across Africa.

The case for international action on air pollution in Africa

The discussion above has proceeded on the implicit assumption that the responsibility for the mitigation of Africa's air pollution lies principally with Africa's national governments. And that is indeed where the *principal* responsibility lies – and especially so in regard to the two general mitigation strategies suggested above. It is national governments that will need to take decisions on the reform of fuel subsidies. And it is national governments that will need to take decisions on public investment in urban improvements.

Nonetheless, as argued in Section I, "local" air pollution is also, and in part, a trans-national and indeed a global problem.

Insofar as air pollutant emissions have trans-national environmental impacts on neighbouring countries, what is required is relatively straight-forward: regional collaboration on research, regional coordination of mitigating actions, and, if necessary, regional co-funding in regard to both research and mitigation.

But that is not the end of the matter.

As detailed in Section I (see above and The Economist, 2015a), "local" air pollution is also, and directly, a contributor to the "global" problem of climate change. Black carbon is a greenhouse pollutant. And black carbon is *inter alia* a product of "open wood fires" – a key component part of Africa's HAP emissions – and of "the exhaust pipes of unsophisticated diesel vehicles" – a key component part of Africa's APMP emissions.

And if Africa's local air pollution is contributing to climate change today, at a time when its population stands at ≈ 1.2 billion, or 16% of the world's population as at 2015, it is safe to suppose that, with unchanged policy settings, it is likely to contribute considerably more when its population increases to ≈ 2.5 billion, or 25% of the world's population in 2050, and thence to ≈ 4.4 billion, or 40% of the world's population in 2100 (United Nations, Department of Economic and Social Affairs, Population Division, 2015).

It is clear therefore that the world as a whole, inclusive of its advanced economies, has an interest in securing the successful mitigation of Africa's air pollution. The question then is how that interest is best translated into action.

And one possible answer to that question is by way of global co-funding of the suggested programme of public investment in urban improvements in Africa.

In this context, it is interesting to recall the triggers to previous cases of massive public investment in urban improvements in the history of the now advanced economies. They include political pressure from below as well as enlightened leadership from above. But they also include the simple fear of contagion. As Costa (2015) explains:

> "The primary explanation of why US citizens spent so much on mortality reductions that disproportionately benefited the poor is that middle class and rich taxpayers viewed public health investments as a type of insurance policy. When the vast majority of a city's employment was located in its downtown and the suburbs were not developed, the rich and poor lived in closer physical proximity, allowing a public health shock in poor neighbourhoods to have a contagion effect on rich neighbourhoods. When whites and blacks lived in close proximity, failing to install water and sewer mains in black neighbourhoods increased the risk of diseases spreading from black neighbourhoods to white ones."

Today, the world's peoples ("rich and poor", "whites and blacks") live in "close proximity" in several respects, including in respect of the common challenge of climate change. It is therefore not unreasonable to suppose that the relatively affluent amongst today's world citizens will be at least as forthcoming in paying their requisite "insurance premiums" as the relatively affluent amongst US citizens in the nineteenth century.

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