APPENDIX E

# Expert Panel Members

Members of the expert panel are listed below. Biographies of each member are provided following the list.

## Expert Panel Members

### W. David Colby, M.D.

Chatham-Kent Medical Officer of Health (Acting)
Associate Professor, Schulich School of Medicine & Dentistry, University of Western Ontario

### Robert Dobie, M.D.

Clinical Professor, University of Texas, San Antonio
Clinical Professor, University of California, Davis

### Geoff Leventhall, Ph.D.

Consultant in Noise Vibration and Acoustics, UK

### David M. Lipscomb, Ph.D.

President, Correct Service, Inc.

### Robert J. McCunney, M.D.

Research Scientist, Massachusetts Institute of Technology Department of Biological Engineering,
Staff Physician, Massachusetts General Hospital Pulmonary Division; Harvard Medical School

### Michael T. Seilo, Ph.D.

Professor of Audiology, Western Washington University

### Bo Søndergaard, M.Sc. (Physics)

Senior Consultant, Danish Electronics Light and Acoustics (DELTA)

## Technical Advisor

### Mark Bastasch

Acoustical Engineer, CH2M HILL

## Panel Member Biographies

### W. David Colby, M.D.

W. David Colby M.Sc., M.D., FRCPC, is a fellow of the Royal College of Physicians and Surgeons of Canada in Medical Microbiology. Dr Colby is the Acting Medical Officer of Health in Chatham-Kent, Ontario and Associate Professor of Medicine, Microbiology/Immunology and Physiology/Pharmacology at the Schulich School of Medicine and Dentistry at the University of Western Ontario. He received his M.D. from the University of Toronto and completed his residency at University Hospital, London, Ontario. While still a resident he was given a faculty appointment and later was appointed Chief of Microbiology and Consultant in Infectious Diseases at University Hospital. Dr Colby lectures extensively on antimicrobial chemotherapy, resistance and fungal infections in addition to a busy clinical practice in Travel Medicine and is a Coroner for the province of Ontario. He has received numerous awards for his teaching. Dr. Colby has a number of articles in peer-reviewed journals and is the author of the textbook *Optimizing Antimicrobial Therapy: A Pharmacometric Approach.* He is a Past President of the Canadian Association of Medical Microbiologists. On the basis of his expertise in Public Health, Dr Colby was asked by his municipality to assess the health impacts of wind turbines. The report, titled *The Health Impact of Wind Turbines: A Review of the Current White,Grey, and Published Literature* is widely cited internationally.

### Robert Dobie, M.D.

Robert Dobie, M.D., is clinical professor of otolaryngology at both the University of Texas Health Science Center at San Antonio and the University of California-Davis. He is also a partner in Dobie Associates, a consulting practice specializing in hearing and balance, hearing conservation, and ear disorders. The author of over 175 publications, his research interests include age-related and noise-induced hearing loss, as well as tinnitus and other inner ear disorders. He is past president of the Association for Research in Otolaryngology, past chair of the Hearing and Equilibrium Committee of the American Academy of Otolaryngology-Head and Neck Surgery, and has served on the boards and councils of many other professional organizations and scholarly journals.

### Geoff Leventhall, Ph.D.

Geoff is a UK-based noise and vibration consultant who works internationally. His academic and professional qualifications include Ph.D. in Acoustics, Fellow of the UK Institute of Physics, Honorary Fellow of the UK institute of Acoustics (of which he is a former President), Distinguished International Member of the USA Institute of Noise Control Engineering, Member of the Acoustical Society of America.

He was formerly an academic, during which time he supervised 30 research students to completion of their doctoral studies in acoustics. Much of his academic and consultancy work has been on problems of infrasound and low frequency noise and control of low frequency noise by active attenuation

He has been a member of a number of National and International committees on noise and acoustics and was recently a member of two committees producing reports on effects of noise on health: the UK Health Protection Agency Committee on the Health Effects of

Ultrasound and Infrasound and the UK Department of Health Committee on the Effects of Environmental Noise on Health.

### David M. Lipscomb, Ph.D.

Dr. David M. Lipscomb received a Ph. D. in Hearing Science from the University of Washington (Seattle) in 1966. Dr. Lipscomb taught at the University of Tennessee for more than two decades in the Department of Audiology and Speech Pathology. While he was on the faculty, Dr. Lipscomb developed and directed the department's Noise Research Laboratory. During his tenure at Tennessee and after he moved to the Pacific Northwest in 1988, Dr. Lipscomb has served as a consultant to many entities including communities, governmental agencies, industries, and legal organizations.

Dr. Lipscomb has qualified in courts of law as an expert in Audiology since 1966. Currently, he investigates incidents to determine whether an acoustical warning signal provided warning to individuals in harms way, and, if so, at how many seconds before an incident. With his background in clinical and research audiology, he undertakes the evaluation of hearing impairment claims for industrial settings and product liability.

Dr. Lipscomb was a bioacoustical consultant to the U. S. Environmental Protection Agency Office of Noise Abatement and Control (ONAC) at the time the agency was responding to Congressional mandates contained in the Noise Control Act of 1972. He was one of the original authors of the Criteria Document produced by ONAC, and he served as a reviewer for the ONAC document titled *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety.* Dr. Lipscomb's experience in writing and reviewing bioacoustical documentation has been particularly useful in his review of materials for AWEA regarding wind farm noise concerns.

### Robert J. McCunney, M.D.

Robert J. McCunney, M.D., M.P.H., M.S., is board certified by the American Board of Preventive Medicine as a specialist in occupational and environmental medicine. Dr. McCunney is a staff physician at Massachusetts General Hospital's pulmonary division, where he evaluates and treats occupational and environmental illnesses, including lung disorders ranging from asbestosis to asthma to mold related health concerns, among others. He is also a clinical faculty member of Harvard Medical School and a research scientist at the Massachusetts Institute of Technology Department of Biological Engineering, where he participates in epidemiological research pertaining to occupational and environmental health hazards.

Dr. McCunney received his B.S. in chemical engineering from Drexel University, his M.S. in environmental health from the University of Minnesota, his M.D. from the Thomas Jefferson University Medical School and his M.P.H. from the Harvard School of Public Health. He completed training in internal medicine at Northwestern University Medical Center in Chicago. Dr. McCunney is past president of the American College of Occupational and Environmental Medicine (ACOEM) and an accomplished author. He has edited numerous occupational and environmental medicine textbooks and over 80 published articles and book chapters. He is the Editor of all three editions of the text book, *A Practical Approach to Occupational and Environmental Medicine,* the most recent edition of which was published in 2003. Dr. McCunney received the Health Achievement Award from ACOEM in 2004.

Dr. McCunney has extensive experience in evaluating the effects of noise on hearing via reviewing audiometric tests. He has written book chapters on the topic and regularly lectures at the Harvard School of Public Health on "Noise and Health."

### Michael T. Seilo, Ph.D.

Dr. Michael T. Seilo received his Ph.D. in Audiology from Ohio University in 1970. He is currently a professor of audiology in the Department of Communication Sciences and Disorders at Western Washington University in Bellingham, Washington where he served as department chair for a total of more than twenty years. Dr. Seilo is clinically certified by the American Speech-Language-Hearing Association (ASHA) in both audiology and speech-language pathology and is a long-time member of ASHA, the American Academy of Audiology, and the Washington Speech and Hearing Association.

For many years Dr. Seilo has taught courses in hearing conservation at both the graduate and undergraduate level. His special interest areas include speech perception and the impact of noise on human hearing sensitivity including tinnitus.

Dr. Seilo has consulted with industries on the prevention of NIHL and he has collaborated with other professionals in the assessment of hearing-loss related claims pertaining to noise.

### Bo Søndergaard, M.Sc. (Physics)

Bo Søndergaard has more than 20 years of experience in consultancy in environmental noise measurements, predictions and assessment. The last 15 years with an emphasis on wind turbine noise. Mr. Søndergaard is the convenor of the MT11 work group under IEC TC88 working with revision of the measurement standard for wind turbines IEC 61400-11. He has also worked as project manager for the following research projects: Low Frequency Noise from Large Wind Turbines for the Danish Energy Authority, Noise and Energy optimization of Wind Farms, and Noise from Wind Turbines in Wake for Energinet.dk.

## Technical Advisor Biography

### Mark Bastasch

Mr. Bastasch is a registered acoustical engineer with CH2M HILL. Mr. Bastasch assisted AWEA and CanWEA in the establishment of the panel and provided technical assistance to the panel throughout the review process. Mr. Bastasch's acoustical experience includes preliminary siting studies, regulatory development and assessments, ambient noise measurements, industrial measurements for model development and compliance purposes, mitigation analysis, and modeling of industrial and transportation noise. His wind turbine experience includes some of the first major wind developments including the Stateline project, which when built in 2001 was the largest in the world. He also serves on the organizing committee of the biannual International Wind Turbine Noise Conference, first held in Berlin, Germany, in 2005.

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# The Impact of Wind Power Projects on Residential Property Values in the United States: A Multi-Site Hedonic Analysis

Ben Hoen, Ryan Wiser, Peter Cappers,
Mark Thayer, and Gautam Sethi

Environmental Energy
Technologies Division

December 2009



The work described in this report was funded by the Office of Energy Efficiency and Renewable Energy (Wind & Hydropower Technologies Program) of the U.S. Department of Energy under Contract No. DE-AC02-05CH1123.

## Disclaimer

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# The Impact of Wind Power Projects on Residential Property Values in the United States: A Multi-Site Hedonic Analysis

Prepared for the

Office of Energy Efficiency and Renewable Energy
Wind & Hydropower Technologies Program
U.S. Department of Energy
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## Abstract

With wind energy expanding rapidly in the U.S. and abroad, and with an increasing number of communities considering wind power development nearby, there is an urgent need to empirically investigate common community concerns about wind project development. The concern that property values will be adversely affected by wind energy facilities is commonly put forth by stakeholders. Although this concern is not unreasonable, given property value impacts that have been found near high voltage transmission lines and other electric generation facilities, the impacts of wind energy facilities on residential property values had not previously been investigated thoroughly. The present research collected data on almost 7,500 sales of single-family homes situated within 10 miles of 24 existing wind facilities in nine different U.S. states. The conclusions of the study are drawn from eight different hedonic pricing models, as well as both repeat sales and sales volume models. The various analyses are strongly consistent in that none of the models uncovers conclusive evidence of the existence of any widespread property value impacts that might be present in communities surrounding wind energy facilities. Specifically, neither the view of the wind facilities nor the distance of the home to those facilities is found to have any consistent, measurable, and statistically significant effect on home sales prices. Although the analysis cannot dismiss the possibility that individual homes or small numbers of homes have been or could be negatively impacted, it finds that if these impacts do exist, they are either too small and/or too infrequent to result in any widespread, statistically observable impact.

## 9. Conclusions

Though surveys generally show that public acceptance towards wind energy is high, a variety of concerns with wind development are often expressed at the local level. One such concern that is often raised in local siting and permitting processes is related to the potential impact of wind projects on the property values of nearby residences.

This report has investigated the potential impacts of wind power facilities on the sales prices of residential properties that are in proximity to and/or that have a view of those wind facilities. It builds and improve on the previous literature that has investigated these potential effects by collecting a large quantity of residential transaction data from communities surrounding a wide variety of wind power facilities, spread across multiple parts of the U.S. Each of the homes included in this analysis was visited to clearly determine the degree to which the wind facility was visible at the time of home sale and to collect other essential data. To frame the analysis, three potentially distinct impacts of wind facilities on property values are considered: Area, Scenic Vista, and Nuisance Stigma. To assess these potential impacts, the authors applied a base hedonic model, explored seven alternative hedonic models, conducted a repeat sales analysis, and evaluated possible impacts on sales volumes. The result is the most comprehensive and data-rich analysis to date on the potential impacts of wind projects on nearby property values.

Although each of the analysis techniques used in this report has strengths and weaknesses, the results are strongly consistent in that each model fails to uncover conclusive evidence of the presence of any of the three property value stigmas. Based on the data and analysis presented in this report, no evidence is found that home prices surrounding wind facilities are consistently, measurably, and significantly affected by either the view of wind facilities or the distance of the home to those facilities. Although the analysis cannot dismiss the possibility that individual or small numbers of homes have been or could be negatively impacted, if these impacts do exist, they are either too small and/or too infrequent to result in any widespread and consistent statistically observable impact. Moreover, to the degree that homes in the present sample are similar to homes in other areas where wind development is occurring, the results herein are expected to be transferable.

Finally, although this work builds on the existing literature in a number of respects, there remain a number of areas for further research. The primary goal of subsequent research should be to concentrate on those homes located closest to wind facilities, where the least amount of data are available. Additional research of the nature reported in this paper could be pursued, but with a greater number of transactions, especially for homes particularly close to wind facilities. Further, it is conceivable that cumulative impacts might exist whereby communities that have seen repetitive development are affected uniquely, and these cumulative effects may be worth investigating. A more detailed analysis of sales volume impacts may also be fruitful, as would an assessment of the potential impact of wind facilities on the length of time homes are on the market in advance of an eventual sale. Finally, it would be useful to conduct a survey of those homeowners living close to existing wind facilities, and especially those residents who have bought and sold homes in proximity to wind facilities after facility construction, to assess their opinions on the impacts of wind project development on their home purchase and sales decisions.

# Energy and Health 2

# Electricity generation and health

*Anil Markandya, Paul Wilkinson*

The provision of electricity has been a great benefit to society, particularly in health terms, but it also carries health costs. Comparison of different forms of commercial power generation by use of the fuel cycle methods developed in European studies shows the health burdens to be greatest for power stations that most pollute outdoor air (those based on lignite, coal, and oil). The health burdens are appreciably smaller for generation from natural gas, and lower still for nuclear power. This same ranking also applies in terms of greenhouse-gas emissions and thus, potentially, to long-term health, social, and economic effects arising from climate change. Nuclear power remains controversial, however, because of public concern about storage of nuclear waste, the potential for catastrophic accident or terrorist attack, and the diversion of fissionable material for weapons production. Health risks are smaller for nuclear fusion, but commercial exploitation will not be achieved in time to help the crucial near-term reduction in greenhouse-gas emissions. The negative effects on health of electricity generation from renewable sources have not been assessed as fully as those from conventional sources, but for solar, wind, and wave power, such effects seem to be small; those of biofuels depend on the type of fuel and the mode of combustion. Carbon dioxide ($CO_2$) capture and storage is increasingly being considered for reduction of $CO_2$ emissions from fossil fuel plants, but the health effects associated with this technology are largely unquantified and probably mixed: efficiency losses mean greater consumption of the primary fuel and accompanying increases in some waste products. This paper reviews the state of knowledge regarding the health effects of different methods of generating electricity.

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This is the second in a **Series** of six papers about energy and health

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## Introduction

Economic growth through industrialisation and rapid technological change has produced a huge improvement in the living standards and health status of the population of the now industrialised countries. From 1820 to 2002, western European countries saw their real incomes per head rise from US$1204 to $19 256, or 16 times.[1] This economic growth was also accompanied by major improvements in health: life expectancy, for example, has risen from around 40 years at the beginning of the 19th century in Europe to nearly 80 years today. The increase in life expectancy is not uniform with income per head of population. It increases rapidly with income up to a level of $7500 and then rises more slowly with further increases in income.[2,3] The availability of modern forms of energy, especially electricity after 1900, has contributed substantially to these positive developments. The replacement of traditional fuels, such as wood and candles, and animal power by steam power, and then by electricity and gas, has reduced the risk of fires, made the air in homes cleaner and warmer in winter, and reduced the risk of health hazards associated with animal waste. Thus it has improved the quality of life of individuals in many ways, and continues to do so in developing countries. A 2001 World Bank study[4] looked at demographic and health data from more than 60 low-income countries and investigated the determinants of health outcomes by use of cross-country data between 1985 and 1999. It found that in urban areas, linking households to electricity is the only key factor that reduced both infant mortality rate and under-5 mortality rate, and that this effect is large, significant, and independent of incomes. In rural areas, improvement

### Key messages

- Access to electricity is pre-requisite for the achievement of health, and lack of access to it remains one of the principal barriers to the fulfilment of human potential and wellbeing
- However, electricity generation from fossil fuel—resources of which could sustain their continued dominant role in electricity production well beyond this century—is also a cause of substantial adverse health burdens
- Fossil-fuel use can be used with greater efficiency than it is currently, and with lower emissions of pollutants harmful to human health. This is especially the case in developing countries, and realising these efficiency gains will be increasingly important as demand for electricity increases sharply
- An accelerated switch to renewable sources has the potential to deliver appreciable health benefits, though a major switch will pose (superable) challenges particularly in relation to the intermittency of renewable production, land use requirements, and cost
- The demand for valuable agricultural land will limit the role of fuel crops in future electricity production in Europe, but the potential contribution of such crops is greater in regions where crops with higher energy yields per hectare can be grown
- Nuclear power has one of the lowest levels of greenhouse-gas emissions per unit power production and one of the smallest levels of direct health effects, yet there are understandable fears about nuclear accidents, weapons uses of fissionable material, and storage of waste; nonetheless, it would add a substantial further barrier to the achievement of urgent reductions in greenhouse gases if the current 17 percent of world electricity generation from nuclear power were allowed to decline
- $CO_2$ capture and storage could in future have an economic role in reducing $CO_2$ emissions from large point sources, but its effects on health are likely to be mixed because efficiency losses mean greater consumption of the primary fuel and other resources, and greater production of waste
- Fusion power offers some hope as a comparatively clean technology for future electricity generation, with environment and health risks that are substantially smaller than for nuclear fission. However, commercial viability is still too far away for it to make a significant contribution to mitigation of climate change over most of this century

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of secondary education for women is crucial for reducing the infant mortality rate, whereas expansion of vaccination coverage reduces the under-5 mortality rate. Even with allowance for the limitations of such cross-sectional studies, the results are noteworthy and not unique.

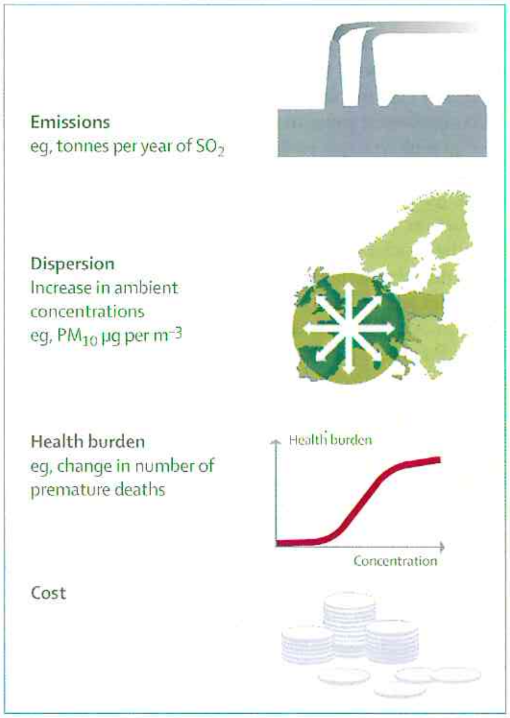


*Figure 1*: The effect pathway approach

| Category of impact on human health | Pollutant or burden | Effects |
|---|---|---|
| Mortality | $PM_{2.5}$, sulphur dioxide, nitrogen oxides, ozone<br>Benzene benzo(a)pyrene<br>1,3-butadiene, diesel particles<br>Accident risk | Reduction in life expectancy<br>Cancers<br>Fatality risk from transport of materials and at workplace |
| Morbidity | $PM_{10}$, sulphur dioxide, ozone<br>$PM_{2.5}$, ozone<br>$PM_{10}$, carbon monoxide<br>Benzene, benzo(a)pyrene<br>1,3-butadiene, diesel particles<br>$PM_{2.5}$<br>Ozone<br>Accident risk | Respiratory hospital admissions<br>Restricted activity days<br>Congestive heart failure<br>Cancer risk (non fatal)<br>Cerebrovascular hospital admissions<br>Cases of chronic bronchitis<br>Cough in asthma patients<br>Lower respiratory symptoms<br>Asthma attacks<br>Symptom days<br>Myocardial infarction<br>Angina pectoris<br>Hypertension<br>Sleep disturbance<br>Risk of injuries from traffic and workplace accidents |

Data taken from ExternE.[6]

*Table 1*: Effect pathways included in analysis of the electricity sector

Electricity has also contributed to economic development more generally by increasing the efficiency with which energy is used, so that an increased level of production is possible with the same amount of energy. Energy use in France, Germany, and the UK increased by 4·7 times between 1840 and 1990, wheres real GDP increased by 21·5 times.[5] Thus each unit of energy now produces more than 4·5 times as much output as it did in 1850.

Overall, there is little doubt that electricity has had a large positive effect on wellbeing. At the same time, new problems have emerged. The burning of large amounts of fossil fuels to produce the electricity we demand generates emissions that are harmful to health and are a source of climate change. Our paper focuses on these issues. We separate the discussion into the situation in developing countries and that in developed countries, and we offer some views on emerging trends in the relation between electricity use and health.

## Assessment of health effects of electricity generation

### Developed countries

The health effects of electricity generation can most easily be assessed by a bottom-up approach, in which emissions and hazards from each stage of the power generation cycle are measured and tracked to the endpoints at which they cause harm to individuals. The effects are calculated for specific technology and location—ie, for a given power station using specified fuel sources.

The effects are referred to as external costs because the party generating the emissions does not take full account of these effects of his or her actions when deciding on how to generate electricity.

Methods based on this approach were first used in the early 1970s and have become increasingly sophisticated. One major set of studies for Europe is the ExternE programme,[6] which is the result of over 15 years of research supported by the European Union (EU) and, to a lesser extent, the USA. ExternE is a bottom-up approach of the kind described above, in which each energy source is assessed individually and its ecological and social footprint analysed. This approach is characterised by the so-called impact pathway, in which emissions from a source are traced through as they disperse into the environment, after which the effects of the dispersed pollutants are estimated. Finally, the health burden is valued in monetary terms where possible. Figure 1 shows this pathway, and table 1 provides a description of the main effects estimated. Several points should be noted about the effects assessed.

Firstly, the emissions from a power source are dispersed into the atmosphere in ways determined by the height of the stack and by weather conditions—ie, temperature, precipitation, and especially wind speed and direction.

| | Deaths from accidents | | Air pollution-related effects | | |
|---|---|---|---|---|---|
| | Among the public | Occupational | Deaths* | Serious illness† | Minor illness‡ |
| Lignite[30] | 0·02 (0·005–0·08) | 0·10 (0·025–0·4) | 32·6 (8·2–130) | 298 (74·6–1193) | 17 676 (4419–70 704) |
| Coal[31] | 0·02 (0·005–0·08) | 0·10 (0·025–0·4) | 24·5 (6·1–98·0) | 225 (56·2–899) | 13 288 (3322–53 150) |
| Gas[31] | 0·02 (0·005–0·08) | 0·001 (0·0003–0·004) | 2·8 (0·70–11·2) | 30 (7·48–120) | 703 (176–2813) |
| Oil[31] | 0·03 (0·008–0·12) | .. | 18·4 (4·6–73·6) | 161 (40·4–645·6) | 9551 (2388–38 204) |
| Biomass[31] | .. | .. | 4·63 (1·16–18·5) | 43 (10·8–172·6) | 2276 (569–9104) |
| Nuclear[31,32] | 0·003 | 0·019 | 0·052 | 0·22 | .. |

Data are mean estimate (95% CI). *Includes acute and chronic effects. Chronic effect deaths are between 88% and 99% of total. For nuclear power, they include all cancer-related deaths. †Includes respiratory and cerebrovascular hospital admissions, congestive heart failure, and chronic bronchitis. For nuclear power, they include all non-fatal cancers and hereditary effects. ‡Includes restricted activity days, bronchodilator use cases, cough, and lower-respiratory symptom days in patients with asthma, and chronic cough episodes. TWh=$10^{12}$ Watt hours.

*Table 2*: Health effects of electricity generation in Europe by primary energy source (deaths/cases per TWh)

Chemistry also plays a part in determining the composition and dispersion of the final product. This dispersion can be simulated by use of complex models that take account not only of the local effects but also of the long-distance transport of the pollutants, through the formation of particles as they are transformed into sulphates and nitrates. Long-distance effects are a substantial proportion of total effects for air pollutants, with the consequence that plants located away from centres of population can have health effects on people living quite far away.

Secondly, the health burden is assessed not just for generation stage but also for the other stages of the full cycle of the process, including the extraction of the fuel, its transportation, transformation into electric energy, disposal of the waste, and the transport of the electricity. So, for example, accidents in transportation are included.

Thirdly, the estimates of air pollution effects are based on extensive peer-reviewed epidemiological studies. Of particular importance are studies linking health effects to concentrations of small particles and ozone (webpanel 1).[7–29]

Fourthly, not all the effects can be valued in money terms, although the most important (ie, health) effects have been. Although monetary valuation remains controversial, especially when applied to health consequences such as premature mortality, methods have been developed to make such valuations and the numbers are used in making decisions about investment in stricter pollution control standards through a comparison of costs and benefits. In this paper, however, we do not report on monetary values for health effects, relying instead only on physical effects data.

Lastly, the scientific data on which the health effects are based are not certain. This uncertainty can be seen in the ranges of effects that are given. As new information becomes available, the values will also change and indeed we have seen some changes in the estimates of health effects over the past 15 years. Table 2 summarises the main health effects that have been estimated for different fuel cycles by the ExternE approach.

Because of the long-range dispersion of the pollutants, some effects can be felt more than 1000 km from the source. The following individual fuel cycles are worth noting.

### *Coal and lignite*

The occupational health effects associated with mining are well known, although the rate of deaths and injuries has been declining. Nevertheless, studies have shown that up to 12% of coal miners develop one of several potentially fatal diseases (pneumoconiosis, progressive massive fibrosis, emphysema, chronic bronchitis, and accelerated loss of lung function).[33]

At the generation stage the main effects arise from the emissions of primary small particles (less than 2·5 μm or $PM_{2.5}$) and the creation of secondary small particles (less than 10 μm or $PM_{10}$). Sulphur dioxide and nitrogen oxides emerge as important in this context because they contribute to the creation of secondary particles, in chemical oxidation involving atmospheric gases. Direct health effects of sulphur dioxide and nitrogen oxides are much less pronounced and are not included in the main estimates reported above.

See Online for webpanel 1

### *Oil and gas*

The health effects from gas are more than an order of magnitude lower than those from coal, mainly because the effects from primary and secondary particles are much smaller. The technologies used in Europe and assessed in our study are also state of the art and very efficient, hence reducing emissions per unit of energy generated. The health burdens associated with oil are higher than those from gas but still much lower than for coal or lignite. Accidents from this fuel source are estimated to be 50% higher than for gas but only 20% of those associated with coal and lignite.

### *Biomass*

The biomass technologies addressed here refer to state of the art plants that meet EU environmental standards (ie, almost all plants that were assessed for the data reported