Population Strategies to Decrease Sodium Intake: A Global Cost-Effectiveness Analysis

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Figure 1. Cost-effectiveness (I$/DALY) by country of an intervention to reduce sodium consumption by 10%.

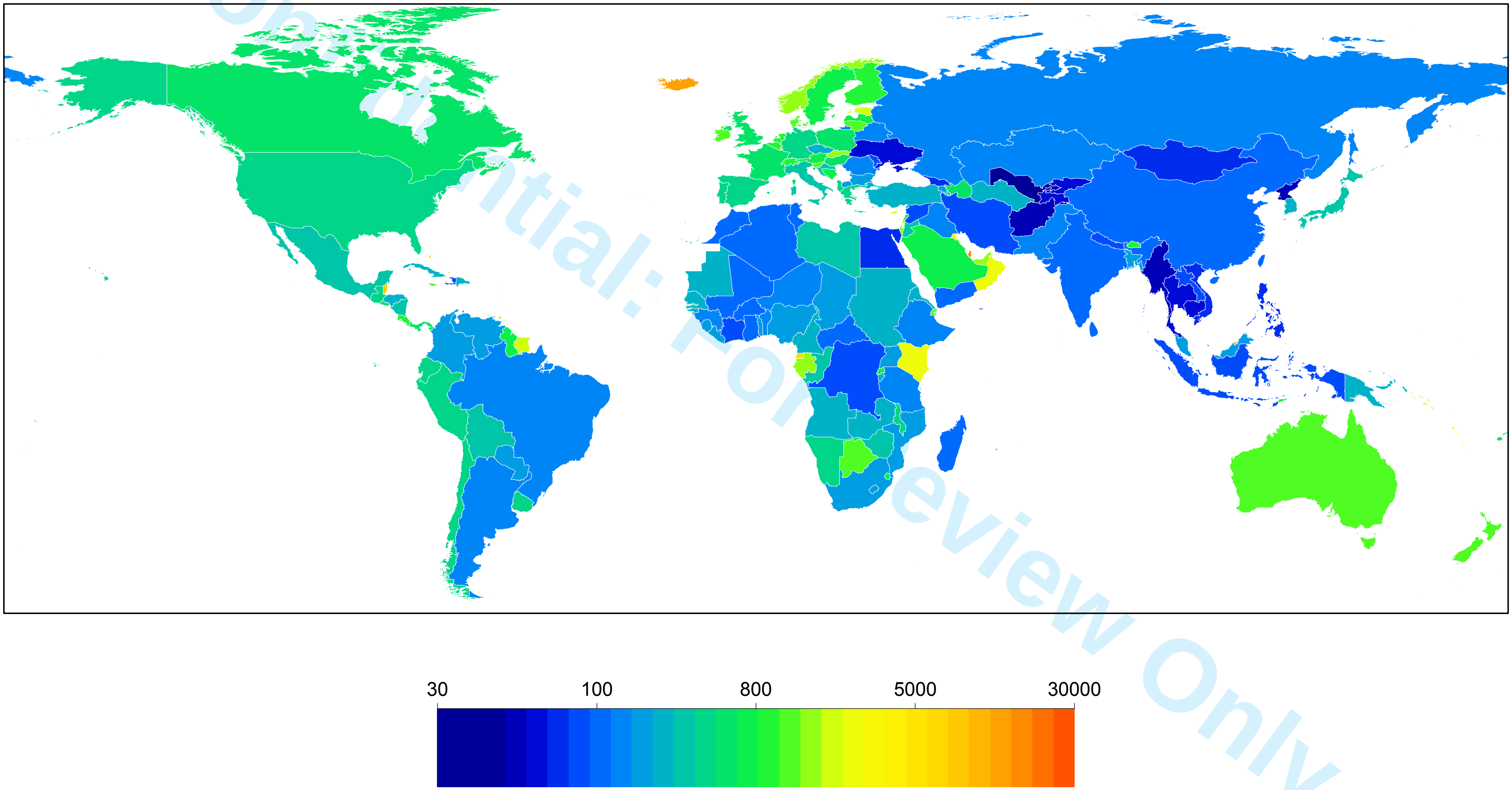


Figure 2. Cost-effectiveness (I$/DALY as a multiple of GDP per capita) by country of an intervention to reduce sodium consumption by 10%.

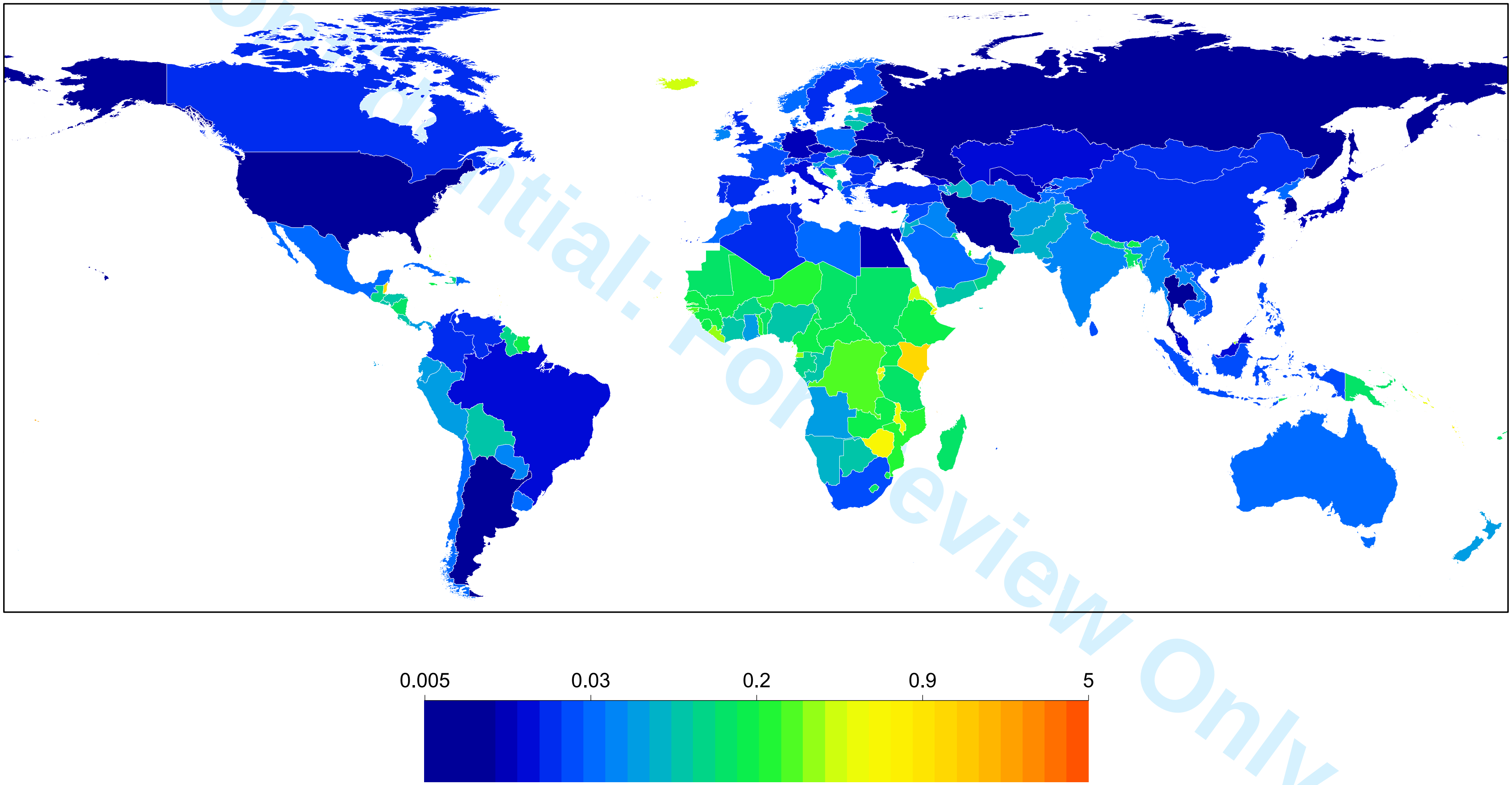
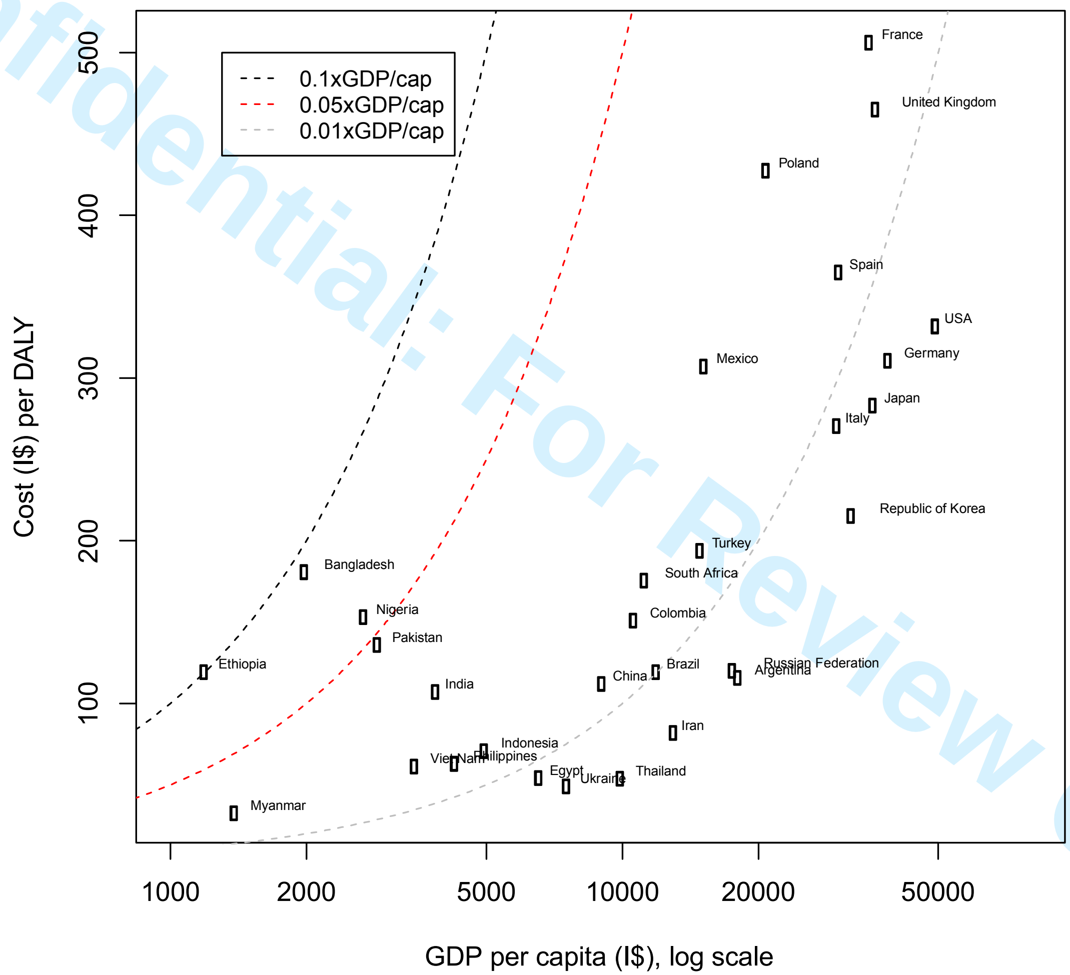


Figure 3. Affordability of an intervention to reduce sodium reduction by 10% in the world's 20 most populous countries.



On-line Only Supplemental Materials

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eMethods

Intervention costs

We estimated component-specific resource costs over 10 years across 4 stages of policy development: planning (year 1), development (year 2), partial implementation (years 3-5), and full implementation (years 6-10). Resource needs at each stage were based on the WHO Non-communicable Disease (NCD) Costing Tool,[1] which uses an 'ingredients approach' to estimation, described in the next section. In the planning stage, resource needs were estimated for preparing an evidence base and launching a public consultation. The development stage included resources for drafting a regulatory code, designing enforcement plans and training programs, and developing a media strategy. Implementation, which begins in year 3, included resources for launching a public information campaign and introducing the regulatory code, followed by staged (partial and then full) regular inspections, enforcement, and media advocacy through year 10. To determine resource needs at each stage, the WHO organized multiple consultations with country-specific program experts and validated their estimates against data from earlier studies. For each stage, quantities were estimated for five categories of resource use: human resources, training, meetings, supplies and equipment, and mass media. Within each category of resource, estimates were made for needs at the central and provincial level. An example of the estimated resource needs for a standardized country of 50 million people, split into provinces of 5 million each, is provided in **eTable 1**.

The WHO-CHOICE database contains information on salaries, per diem allowances (for training and meetings), media costs, and consumable item prices for each country. These data were estimated from consultation with regional expert teams, supplemented where possible with other sources, including the International Labour Organization database on occupational salaries. Prices of non-traded goods were derived using linear regression models fitted to a multinational dataset, with GDP per capita, region, and education levels among others used as explanatory variables.[2]

We converted the 2008 WHO NCD Costing Tool estimates to 2012 international dollars by first accounting for local inflation based on World Bank GDP deflator figures,[3] then using 2012 PPP exchange rates from the IMF World Economic Outlook Database.[4] We also updated the underlying data used to predict non-traded good prices, in particular countries' GDP per capita.

Global sodium consumption by country, age, and sex

We used estimates of mean sodium consumption and its uncertainty by age and sex for 187 countries from the 2010 Global Burden of Diseases (GBD) project.[5] These data were based on 205 national and subnational surveys, covering 66 countries and 74.1% of the global adult population. The main metric used was 24-hour urine collection, which might underestimate intake due to non-urinary (e.g., sweat) losses. An age-integrating Bayesian hierarchical imputation model was used to account for differences in missingness, representativeness, and measurement methods between the surveys, and to quantify sampling and modeling uncertainty. The final uncertainty intervals published represent the 2.5–97.5 percentiles of the posterior distribution of estimated mean sodium intakes for each age/sex stratum in each country, and we used these as inputs to our analysis.

Blood pressure levels by country, age, and sex

We used estimates of mean systolic blood pressure (SBP) levels and their uncertainties by age and sex for 187 countries, also from the 2010 GBP project.[6] Data were obtained from published and unpublished health examination surveys and epidemiological studies from around the world, including data from 786 country-years and 5.4 million participants. A Bayesian hierarchical model was developed to obtain estimates for each age-country-year unit. Estimates were made for the years 1980 to 2008; we used the 2008 estimates for our calculations. Similar to the model used for sodium, the model borrowed information across countries, subregions, and regions, according to 'proximity' in geography, time, and country-level covariates, doing so to a greater degree when data were non-existent or non-informative. Various sources of uncertainty were quantified and propagated through the model. The final uncertainty intervals published represent the 2.5–97.5 percentiles of the posterior distribution of estimated mean SBP, and we used these as inputs to our analysis.

Cardiovascular disease burden by country, age, and sex

We used data on disability-adjusted life years (DALYs) for 11 causes, 7 age groups, both sexes, and 187 countries, also from the 2010 Global Burden of Diseases study.[7] These causes were ischemic heart disease

(ICD-10 codes I20-I25), ischemic stroke (I63, I65-I67, I69.3), hemorrhagic and other non-ischemic stroke (I60-I62, I69.0-I69.2, I67.4), hypertensive heart disease (I11-I13), aortic aneurysm (I71), rheumatic heart disease (I01, I02.0, I05-I09), endocarditis (I33), atrial fibrillation and flutter (I48), peripheral vascular disease (I73), myocarditis and cardiomyopathy (I40, I42), and other cardiovascular and circulatory diseases. These data were obtained by first estimating cause-specific mortality for 187 countries from 1980 to 2010,[89] based on data on causes of death from vital registration, verbal autopsy, mortality surveillance, censuses, surveys, hospitals, police records, and mortuaries worldwide. Next, the prevalence of disease-sequelae (impairments of health resulting from a disease) was estimated by conducting a systematic analysis of published and available unpublished data sources for prevalence, incidence, remission, and excess mortality, and aggregating this data using a Bayesian meta-regression model, developed from those described above. Finally, disability weights were generated using data collected from more than 31,000 respondents via population-based surveys in the USA, Peru, Tanzania, Bangladesh, and Indonesia, and via an open internet survey. Results were found to be consistent across levels of educational attainment and cultural groups.[10]

Dose-response effects of sodium on BP and of BP on CVD

We used estimates of dose-response effects of sodium on BP and of BP on CVD from recently published meta-analyses. The first used results from 103 randomized trials, with a total of 6,970 subjects, to estimate the blood pressure-lowering effect of sodium reduction. [11] The study tested and confirmed the linearity of the effect, and quantified heterogeneity owing to age, hypertensive status, and race, all of which were found to be significant, and duration of intervention, which was not. We used coefficients estimated in a regression incorporating these first three covariates, together with their standard errors, as inputs to our analysis. The second meta-analysis combined results from the Prospective Studies Collaborative (61 cohorts, 1 million participants, 120,000 deaths) and the Asia Pacific Cohort Studies Collaborative (37 cohorts, 425,000 participants, 6,900 deaths) to estimate the effect of blood pressure on cardiovascular diseases by age.[12] A linear relationship between age and log relative risk was found to have the best fit among a range of models. Monte Carlo simulations were used to estimate relative risks and their standard errors. Age-specific relative risks obtained in this way from the different sources were then pooled using a random effects model. We used these age-specific relative risks, together with their standard errors, as inputs to our analysis.

While some prior observational studies suggest a J-shaped relation between sodium intake and CVD, the potential biases of sodium assessment in observational studies are appreciated. These include incomplete 24-hour urine collections among sicker individuals, which causes a spurious association between low estimated intake and disease risk; reverse causation among at-risk subjects, especially those with high blood pressure, who are both at higher risk and also choose to actively lower their sodium; confounding by physical activity, given the strong positive correlation between sodium intake and total energy intake; and confounding by general health and appetite, due to the same strong correlation between sodium intake and total energy intake.

Intervention impact on disability-adjusted life years (DALYs)

Within each age-sex-country stratum, we calculated the proportion of DALYs attributable to CVD that would be averted if the existing distribution of systolic BP were shifted to lower levels due to reduced sodium consumption. We then multiplied this potential impact fraction by the total number of DALYs that were attributable to CVD in 2010. We performed these analyses separately for each subtype of CVD event (e.g., ischemic heart disease, ischemic stroke, hemorrhagic stroke, etc.). We assumed the intervention would scale up linearly over the implementation period, with 10% of the full effect in the first year, 20% in the second, and so on, reaching full efficacy in the final year. We summed these yearly effects, discounting at 3% per year, to calculate the total effect. We assumed no other changes, other than related to the intervention, on global sodium consumption, BP levels, or CVD rates during this period.

eDiscussion

Strengths of the analysis

Our analysis has several strengths. We used comparable and consistent methods to estimate the cost-effectiveness of a sodium reduction policy intervention for 183 countries. We utilized the most up-to-date available data on age, sex, and country-specific distributions of sodium consumption, BP, and rates of CVD. Effects of sodium reduction on BP were derived from a meta-analysis of randomized controlled trials, accounting for heterogeneity by age, race, and hypertension; and estimates of the age-specific relationship between BP-lowering and CVD was derived from a pooled analysis of established prospective pooling projects. We accounted for a 10-year intervention effect with a realistic scale-up trajectory and reasonable target reductions in sodium. We used a tool developed by the WHO to estimate the different quantities and costs of intervention components by country. These estimates incorporated country-specific demographic, economic, and health data, together with results from cross-country non-traded input price regressions, to produce credible approximations of these prices. We accounted for changes in GDP/capita, price levels, and purchasing power parity between countries. We incorporated uncertainty in all effect input parameters (measures of sodium exposure, distributions of BP, effects of sodium on BP, effects of BP on CVD) by means of Monte Carlo simulations, and evaluated additional uncertainty in intervention effectiveness and intervention costs by means of separate sensitivity analyses.

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eTable 1. Resource needs for sodium reduction intervention for an example[a] country.

	Administrative level (Standardized population, in millions)	Planning (year 1) National (50m)	Planning (year 1) Province (5m)	Development (year 2) National (50m)	Development (year 2) Province (5m)	Partial implementation (years 3-5) National (50m)	Partial implementation (years 3-5) Province (5m)	Full implementation (years 6-10) National (50m)	Full implementation (years 6-10) Province (5m)
HUMAN RESOURCES (incl. consultants)	***Roles / responsibilities***	FTE[b]	FTE	FTE	FTE	FTE	FTE	FTE	FTE
Program management									
Director	*Oversight; Monitoring; Reporting*	0.125	0.0625	0.125	0.0625	0.125	0.0625	0.125	0.0625
Manager	*Oversight; Monitoring; Reporting*	0.25	0.125	0.25	0.125	0.25	0.125	0.25	0.125
Administrative officer	*Data collection; Monitoring*	0.5	0.25	0.5	0.25	0.5	0.25	0.5	0.25
Clerical officer	*Data collection; Monitoring*	1	0.5	1	0.5	1	0.5	1	0.5
Secretary	*Office support*	0.9	0.4	0.9	0.4	0.9	0.4	0.9	0.4
Accountant	*Financial data entry/analysis*	0.25	0.125	0.25	0.125	0.25	0.125	0.25	0.125
I.T. computing manager	*I.T. support*	0.125	0.0625	0.125	0.0625	0.125	0.0625	0.125	0.0625
I.T. computing officer	*I.T. support*	0.25	0.125	0.25	0.125	0.25	0.125	0.25	0.125
Cleaner	*General office maintenance*	0.25	0	0.25	0	0.25	0	0.25	0
Subtotal		3.6	1.7	3.6	1.7	3.6	1.7	3.6	1.7
Promotion / media / advocacy									
Public health specialist	*Advocacy; Dissemination*	0.25	0.125	0.25	0.25	0.25	0.125	0.25	0.125
Public health officer	*Admin / research support*	0.5	0.25	0.5	0.5	0.5	0.25	0.5	0.25
Health educator/trainer	*Advocacy; Dissemination*	0.5	0.25	0.5	0.5	0.5	0.25	0.5	0.25
Public Relations Manager		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Public Relations Officer		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Subtotal		2.0	1.4	2.0	2.0	2.0	1.4	2.0	1.4
Law enforcement / inspection									
Superintendent	*Supervision of new (voluntary) code*			0.25	0.25	0.5	0.5	0.5	0.5
Enforcement / health safety officer	*Inspection*			1	1	2	2	2	2
Lawyer	*Development of new code*	1	0.5	1	0.25	0.25	0.125	0.25	0.125
Legal Officer	*Development of new code*	2	1	2	0.5	0.5	0.25	0.5	0.25
Transport manager	*Transport support*	0.2	0.1	0.3	0.1	0.2	0.1	0.2	0.1
Transport driver	*Transport support*	0.9	0.5	1.1	0.6	0.8	0.6	0.8	0.6
Subtotal		4.2	2.2	5.6	2.7	4.3	3.6	4.3	3.6
National-level technical assistance	*(local planning / implementation)*								
International consultant (No. of 5-day trips p.a.)		2		2		1		1	
TOTAL HUMAN RESOURCES		9.8	5.2	11.2	6.4	9.9	6.7	9.9	6.7

a. Example country is assumed to have a population of 50 million, split into provinces of 5 million each.
a. Full-time equivalent.

eTable 1. Resource needs for sodium reduction intervention for an example country (continued).

		Planning (year 1)		Development (year 2)		Partial implementation (years 3-5)		Full implementation (years 6-10)	
	Administrative level (Standardised population, in millions)	**National** (50m)	**Province** (5m)	**National** (50m)	**Province** (5m)	**National** (50m)	**Province** (5m)	**National** (50m)	**Province** (5m)
TRAINING (for programme staff)	***Purpose***								
Training course / workshop (1)	*(sodium and public health)*								
Frequency of meetings (expressed per year)		1	1	1	1	1	1	1	1
Number of meetings needed (within the year)		2	1	2	2	1	2	1	2
Length of meetings (days)		2	2	2	2	2	2	2	2
National experts in attendance (No., per diem, travel cost)		2	1	2	1	2	1	4	1
Local experts in attendance (No., per diem, travel cost)		20	15	20	15	20	15	20	15
Training course / workshop (2)	*(food inspection)*								
Frequency of meetings (expressed per year)					1		1		1
Number of meetings needed (within the year)					2		1		1
Length of meetings (days)					3		2		2
National experts in attendance (No., per diem, travel cost)					2		1		1
Local experts in attendance (No., per diem, travel cost)					15		15		15
MEETINGS (involving external agencies)	***Purpose***								
Meetings / workshops (1)	*(planning, + M&E)*								
Frequency of meetings (expressed per year)		1	1	1	1	1	1	1	0.5
Number of meetings needed (within the year)		3	1	2	1	2	1	2	1
Length of meetings (days)		3	3	3	3	2	2	2	2
National experts in attendance (No., per diem, travel cost)		4	3	4	2	4	1	4	1
Local experts in attendance (No., per diem, travel cost)		15	10	15	10	15	10	15	10
MASS MEDIA									
Television time (minutes)				150		150		150	
Radio time (minutes)				200	150	150	100	150	100
Newspapers (100 word insert)				60	30	60	30	60	30
Flyers / leaflets					20,000		15,000		15,000

eTable 2. Cost-effectiveness by country of a policy intervention to reduce sodium consumption by 10%.

Country[a]	DALYs averted (95% UI)	Cost/capita	CER (95% UI)[b]	CE/GDP	DALYs /1000 adults
Afghanistan	158,653 (96,533, 215,189)	$0.55	$36.39 ($59.81, $26.83)	0.04	15.1
Albania	16,319 (10,461, 22,097)	$2.89	$332.72 ($519.06, $245.73)	0.04	8.7
Algeria	107,283 (67,357, 146,916)	$0.54	$94.14 ($149.95, $68.75)	0.01	5.8
Andorra	272 (171, 370)	$121.42	$27,027.80 ($43,026.24, $19,847.69)	0.73	4.5
Angola	38,426 (23,120, 54,392)	$1.25	$208.86 ($347.13, $147.55)	0.03	6
Antigua and Barbuda	171 (106, 241)	$60.14	$16,618.77 ($26,802.34, $11,813.69)	0.95	3.6
Argentina	111,450 (71,479, 153,335)	$0.55	$116.32 ($181.36, $84.54)	0.01	4.7
Armenia	24,967 (16,468, 33,555)	$2.04	$155.06 ($235.08, $115.38)	0.03	13.2
Australia	42,067 (26,751, 57,251)	$2.48	$858.76 ($1,350.46, $631.01)	0.02	2.9
Austria	28,902 (18,470, 39,581)	$2.83	$600.41 ($939.52, $438.42)	0.01	4.7
Azerbaijan	68,292 (44,129, 89,484)	$5.65	$442.07 ($684.12, $337.37)	0.04	12.8
Bahamas	672 (414, 937)	$24.34	$7,428.39 ($12,043.73, $5,327.12)	0.24	3.3
Bahrain	2,313 (1,491, 3,105)	$12.71	$4,511.28 ($7,000.09, $3,360.83)	0.16	2.8
Bangladesh	254,523 (157,903, 355,833)	$0.64	$181.39 ($292.38, $129.75)	0.09	3.5
Barbados	827 (529, 1,123)	$21.96	$4,938.55 ($7,714.75, $3,635.51)	0.19	4.4
Belarus	134,779 (87,212, 182,545)	$2.52	$127.11 ($196.44, $93.85)	0.01	19.8
Belgium	33,266 (21,593, 45,300)	$3.27	$755.44 ($1,163.84, $554.76)	0.02	4.3
Belize	384 (235, 525)	$21.32	$7,559.40 ($12,366.03, $5,523.37)	0.9	2.8
Benin	19,727 (12,046, 27,679)	$0.87	$142.99 ($234.17, $101.92)	0.08	6.1
Bhutan	1,417 (889, 1,941)	$2.67	$671.44 ($1,069.95, $490.05)	0.1	4
Bolivia	19,224 (12,032, 26,395)	$1.11	$250.66 ($400.50, $182.56)	0.05	4.4
Bosnia and Herzegovina	22,506 (14,529, 30,856)	$5.29	$628.89 ($974.20, $458.70)	0.08	8.4
Botswana	4,154 (2,408, 5,955)	$3.99	$872.78 ($1,505.99, $608.89)	0.05	4.6
Brazil	755,263 (494,700, 1,011,356)	$0.81	$119.97 ($183.16, $89.59)	0.01	6.8
Brunei Darussalam	923 (595, 1,243)	$44.20	$10,917.91 ($16,944.36, $8,106.95)	0.22	4
Bulgaria	87,451 (56,737, 117,077)	$2.77	$177.66 ($273.84, $132.71)	0.01	15.6
Burkina Faso	32,320 (19,592, 45,061)	$0.56	$97.60 ($161.00, $70.00)	0.07	5.7
Burundi	9,065 (4,273, 14,723)	$0.53	$194.56 ($412.75, $119.79)	0.32	2.7
Cambodia	64,460 (42,030, 85,353)	$0.51	$51.31 ($78.70, $38.75)	0.02	10
Cameroon	26,993 (15,380, 39,560)	$0.81	$227.47 ($399.22, $155.21)	0.1	3.6
Canada	86,609 (55,244, 116,240)	$1.86	$503.88 ($789.96, $375.43)	0.01	3.7
Cape Verde	1,508 (932, 2,057)	$10.47	$1,557.11 ($2,518.26, $1,141.63)	0.38	6.7
Central African Republic	16,694 (10,514, 23,099)	$0.89	$91.71 ($145.62, $66.28)	0.11	9.7

Chad	22,085 (13,373, 30,675)	$0.94	$166.73 ($275.35, $120.04)	0.08	5.6
Chile	26,986 (16,976, 37,911)	$1.03	$386.38 ($614.21, $275.04)	0.02	2.7
China	6,598,540 (4,460,556, 8,624,043)	$0.87	$112.76 ($166.80, $86.27)	0.01	7.7
Colombia	105,836 (70,158, 140,949)	$0.65	$151.59 ($228.69, $113.83)	0.01	4.3
Comoros	542 (270, 896)	$5.15	$2,740.90 ($5,501.36, $1,657.86)	2.11	1.9
Congo	11,034 (6,148, 16,306)	$1.87	$273.78 ($491.40, $185.27)	0.06	6.8
Costa Rica	6,567 (4,112, 9,075)	$1.89	$754.64 ($1,205.20, $546.10)	0.06	2.5
Côte d'Ivoire	65,684 (39,219, 91,670)	$0.73	$85.34 ($142.92, $61.15)	0.05	8.6
Croatia	27,603 (17,355, 37,275)	$2.26	$262.60 ($417.68, $194.47)	0.01	8.6
Cuba	30,666 (19,183, 43,265)	$0.90	$225.83 ($361.01, $160.06)	0.02	4
Cyprus	2,499 (1,630, 3,396)	$15.07	$3,004.96 ($4,606.02, $2,211.14)	0.11	5
Czech Republic	59,174 (38,802, 79,566)	$1.80	$234.06 ($356.95, $174.08)	0.01	7.7
Democratic People's Republic of Korea	131,411 (83,091, 179,293)	$0.31	$35.58 ($56.28, $26.08)	0.02	8.8
Democratic Republic of the Congo	142,703 (84,788, 207,796)	$0.51	$79.55 ($133.89, $54.63)	0.2	6.5
Denmark	15,502 (10,022, 21,436)	$3.50	$868.67 ($1,343.72, $628.20)	0.02	4
Djibouti	1,840 (1,077, 2,660)	$4.92	$1,011.93 ($1,729.21, $699.98)	0.37	4.9
Dominica	140 (85, 196)	$50.03	$14,194.71 ($23,422.99, $10,111.66)	0.97	3.5
Dominican Republic	21,721 (13,216, 30,916)	$0.90	$206.79 ($339.86, $145.29)	0.02	4.4
Ecuador	19,709 (12,102, 28,019)	$0.84	$313.01 ($509.77, $220.18)	0.04	2.7
Egypt	455,019 (287,380, 624,452)	$0.63	$54.78 ($86.73, $39.91)	0.01	11.5
El Salvador	9,381 (5,739, 13,236)	$1.39	$424.80 ($694.37, $301.06)	0.06	3.3
Equatorial Guinea	1,259 (710, 1,876)	$21.54	$4,956.41 ($8,786.29, $3,324.73)	0.25	4.3
Eritrea	9,945 (5,754, 14,519)	$1.04	$209.13 ($361.42, $143.24)	0.26	4.9
Estonia	10,405 (6,738, 13,983)	$17.00	$1,555.00 ($2,401.25, $1,157.14)	0.07	10.9
Ethiopia	127,441 (76,004, 187,775)	$0.49	$120.00 ($201.22, $81.44)	0.1	4.1
Fiji	4,037 (2,396, 5,833)	$3.82	$427.99 ($720.97, $296.21)	0.09	8.9
Finland	22,091 (14,431, 29,758)	$3.82	$659.14 ($1,009.06, $489.32)	0.02	5.8
France	147,200 (95,540, 198,883)	$1.72	$506.75 ($780.75, $375.06)	0.01	3.4
Gabon	2,855 (1,447, 4,370)	$5.42	$1,239.27 ($2,445.36, $809.84)	0.07	4.4
Gambia	3,849 (2,343, 5,315)	$2.42	$385.74 ($633.61, $279.32)	0.2	6.3
Georgia	63,063 (41,707, 82,849)	$1.33	$61.47 ($92.95, $46.79)	0.01	21.6
Germany	299,996 (190,382, 407,770)	$1.51	$311.28 ($490.49, $229.01)	0.01	4.8
Ghana	58,679 (34,476, 85,086)	$0.64	$110.67 ($188.35, $76.32)	0.03	5.8
Greece	49,044 (30,988, 67,584)	$2.10	$364.13 ($576.30, $264.24)	0.01	5.8
Grenada	266 (164, 380)	$51.37	$10,071.49 ($16,394.71, $7,054.24)	0.71	5.1
Guatemala	14,381 (8,813, 20,302)	$0.96	$366.91 ($598.74, $259.90)	0.07	2.6

Guinea	24,046 (14,384, 34,081)	$0.79	$121.85 ($203.69, $85.97)	0.11	6.5
Guinea-Bissau	4,989 (2,968, 6,970)	$1.67	$196.81 ($330.84, $140.87)	0.18	8.5
Guyana	2,606 (1,525, 3,706)	$4.12	$574.57 ($981.56, $404.02)	0.07	7.2
Haiti	34,727 (21,208, 48,736)	$0.69	$85.74 ($140.39, $61.09)	0.07	8.1
Honduras	14,638 (8,993, 20,374)	$1.11	$241.07 ($392.41, $173.20)	0.05	4.6
Hungary	89,765 (59,278, 119,425)	$5.28	$428.94 ($649.55, $322.41)	0.02	12.3
Iceland	592 (370, 808)	$29.40	$10,405.03 ($16,616.50, $7,622.12)	0.26	2.8
India	4,284,301 (2,768,629, 5,789,032)	$0.75	$107.80 ($166.81, $79.78)	0.03	7
Indonesia	987,857 (622,578, 1,348,436)	$0.54	$71.48 ($113.42, $52.37)	0.01	7.5
Iran (Islamic Republic of)	277,532 (174,670, 376,502)	$0.56	$82.54 ($131.14, $60.84)	0.01	6.8
Iraq	86,044 (55,224, 118,300)	$0.96	$131.62 ($205.07, $95.73)	0.03	7.3
Ireland	11,239 (7,195, 15,135)	$3.79	$1,004.23 ($1,568.61, $745.69)	0.02	3.8
Israel	13,428 (8,563, 18,370)	$3.47	$1,111.17 ($1,742.60, $812.25)	0.03	3.1
Italy	228,308 (146,844, 310,253)	$1.36	$271.20 ($421.65, $199.57)	0.01	5
Jamaica	2,720 (1,625, 3,950)	$1.85	$985.31 ($1,648.64, $678.45)	0.11	1.9
Japan	443,744 (301,526, 586,860)	$1.31	$283.75 ($417.59, $214.55)	0.01	4.6
Jordan	15,076 (9,730, 20,531)	$1.67	$280.68 ($434.88, $206.10)	0.05	5.9
Kazakhstan	209,394 (142,270, 271,379)	$3.08	$133.96 ($197.17, $103.36)	0.01	23
Kenya	5,995 (2,871, 10,199)	$0.76	$1,873.89 ($3,913.69, $1,101.54)	1.04	0.4
Kiribati	209 (118, 320)	$53.01	$10,280.08 ($18,146.73, $6,718.15)	1.74	5.2
Kuwait	6,856 (4,135, 9,658)	$12.92	$2,982.06 ($4,943.76, $2,116.92)	0.07	4.3
Kyrgyzstan	41,594 (27,525, 55,013)	$0.76	$45.91 ($69.37, $34.71)	0.02	16.5
Lao People's Democratic Republic	26,932 (17,070, 36,030)	$0.75	$73.24 ($115.55, $54.75)	0.02	10.2
Latvia	23,136 (15,017, 31,341)	$8.45	$591.35 ($911.07, $436.54)	0.03	14.3
Lebanon	11,997 (7,675, 16,472)	$2.59	$523.46 ($818.27, $381.25)	0.03	5
Lesotho	8,345 (4,926, 11,739)	$1.83	$187.30 ($317.26, $133.14)	0.09	9.8
Liberia	7,396 (4,267, 10,538)	$0.80	$160.34 ($277.94, $112.54)	0.23	5
Libyan Arab Jamahiriya	24,662 (15,318, 34,145)	$2.10	$281.05 ($452.50, $202.99)	0.02	7.5
Lithuania	27,583 (17,467, 37,565)	$11.44	$969.30 ($1,530.68, $711.74)	0.05	11.8
Luxembourg	1,522 (1,007, 2,062)	$31.48	$7,287.41 ($11,010.99, $5,379.54)	0.09	4.3
Macedonia (Former Yugoslav Republic of)	16,515 (10,920, 22,183)	$2.10	$175.82 ($265.90, $130.90)	0.02	11.9
Madagascar	58,713 (33,021, 86,318)	$0.69	$90.63 ($161.15, $61.65)	0.09	7.6
Malawi	11,411 (5,913, 18,455)	$0.82	$359.92 ($694.55, $222.54)	0.4	2.3
Malaysia	91,442 (59,142, 125,363)	$0.97	$155.54 ($240.49, $113.46)	0.01	6.2
Maldives	367 (230, 510)	$13.24	$5,569.16 ($8,878.50, $4,009.70)	0.64	2.4
Mali	36,483 (21,814, 51,466)	$0.79	$110.77 ($185.25, $78.52)	0.1	7.2

Malta	1,459 (947, 1,940)	$17.91	$3,620.52 ($5,579.75, $2,722.73)	0.14	4.9
Marshall Islands	151 (87, 211)	$84.54	$15,069.42 ($26,189.19, $10,757.07)	4.71	5.6
Mauritania	8,787 (5,429, 12,366)	$1.20	$189.91 ($307.40, $134.95)	0.09	6.3
Mauritius	11,493 (8,006, 14,108)	$3.60	$249.91 ($358.75, $203.57)	0.02	14.4
Mexico	156,362 (97,089, 215,496)	$0.81	$307.75 ($495.63, $223.30)	0.02	2.6
Micronesia (Federated States of)	303 (186, 433)	$42.06	$6,310.99 ($10,250.47, $4,415.14)	2.1	6.7
Moldova	36,855 (23,764, 49,691)	$1.40	$88.66 ($137.50, $65.76)	0.03	15.8
Mongolia	26,478 (16,925, 35,035)	$1.15	$60.54 ($94.72, $45.76)	0.01	18.9
Montenegro	4,411 (2,848, 5,970)	$26.22	$2,487.13 ($3,852.71, $1,837.64)	0.21	10.5
Morocco	107,021 (69,911, 143,478)	$0.65	$102.10 ($156.30, $76.16)	0.02	6.4
Mozambique	29,216 (16,920, 43,243)	$0.60	$173.61 ($299.78, $117.30)	0.14	3.4
Myanmar	246,217 (162,515, 326,712)	$0.31	$33.30 ($50.46, $25.10)	0.02	9.2
Namibia	8,595 (5,241, 11,944)	$2.86	$321.97 ($528.04, $231.70)	0.04	8.9
Nepal	61,800 (38,769, 84,742)	$0.40	$83.83 ($133.63, $61.13)	0.06	4.8
Netherlands	37,631 (24,256, 51,252)	$2.24	$693.93 ($1,076.58, $509.51)	0.02	3.2
New Zealand	9,639 (6,170, 13,177)	$3.36	$989.45 ($1,545.86, $723.77)	0.03	3.4
Nicaragua	9,364 (5,915, 12,724)	$1.00	$272.20 ($430.90, $200.32)	0.08	3.7
Niger	30,201 (17,764, 42,016)	$0.71	$120.24 ($204.43, $86.43)	0.13	5.9
Nigeria	253,603 (154,353, 357,516)	$0.65	$153.80 ($252.69, $109.10)	0.06	4.2
Norway	12,433 (7,891, 17,399)	$4.30	$1,145.40 ($1,804.68, $818.48)	0.02	3.8
Oman	5,114 (3,106, 7,235)	$7.26	$2,010.51 ($3,309.73, $1,421.03)	0.07	3.6
Pakistan	461,242 (289,095, 629,447)	$0.84	$136.62 ($217.98, $100.11)	0.05	6.2
Panama	6,698 (4,264, 9,086)	$1.65	$465.37 ($731.07, $343.08)	0.03	3.5
Papua New Guinea	8,894 (4,932, 12,906)	$0.69	$223.50 ($403.03, $154.03)	0.08	3.1
Paraguay	20,559 (13,571, 27,307)	$1.12	$161.99 ($245.40, $121.96)	0.03	6.9
Peru	32,151 (20,070, 45,102)	$0.74	$339.43 ($543.75, $241.97)	0.03	2.2
Philippines	406,809 (262,442, 542,698)	$0.62	$63.56 ($98.52, $47.64)	0.01	9.8
Poland	236,199 (154,876, 315,240)	$3.74	$427.97 ($652.69, $320.66)	0.02	8.7
Portugal	40,519 (26,798, 55,034)	$1.64	$317.07 ($479.43, $233.45)	0.01	5.2
Qatar	1,719 (1,038, 2,433)	$19.10	$14,056.69 ($23,275.52, $9,932.23)	0.14	1.4
Republic of Korea	139,348 (93,766, 181,597)	$0.89	$215.82 ($320.73, $165.61)	0.01	4.1
Romania	215,036 (139,641, 284,900)	$2.06	$146.93 ($226.25, $110.90)	0.01	14
Russian Federation	1,874,746 (1,218,294, 2,520,416)	$2.27	$120.65 ($185.66, $89.74)	0.01	18.8
Rwanda	5,008 (2,186, 8,894)	$0.79	$614.80 ($1,408.22, $346.18)	0.44	1.3
Saint Lucia	375 (235, 517)	$26.71	$6,755.78 ($10,774.11, $4,900.44)	0.51	4
Saint Vincent and the Grenadines	265 (163, 371)	$35.70	$8,068.08 ($13,144.57, $5,770.83)	0.68	4.4

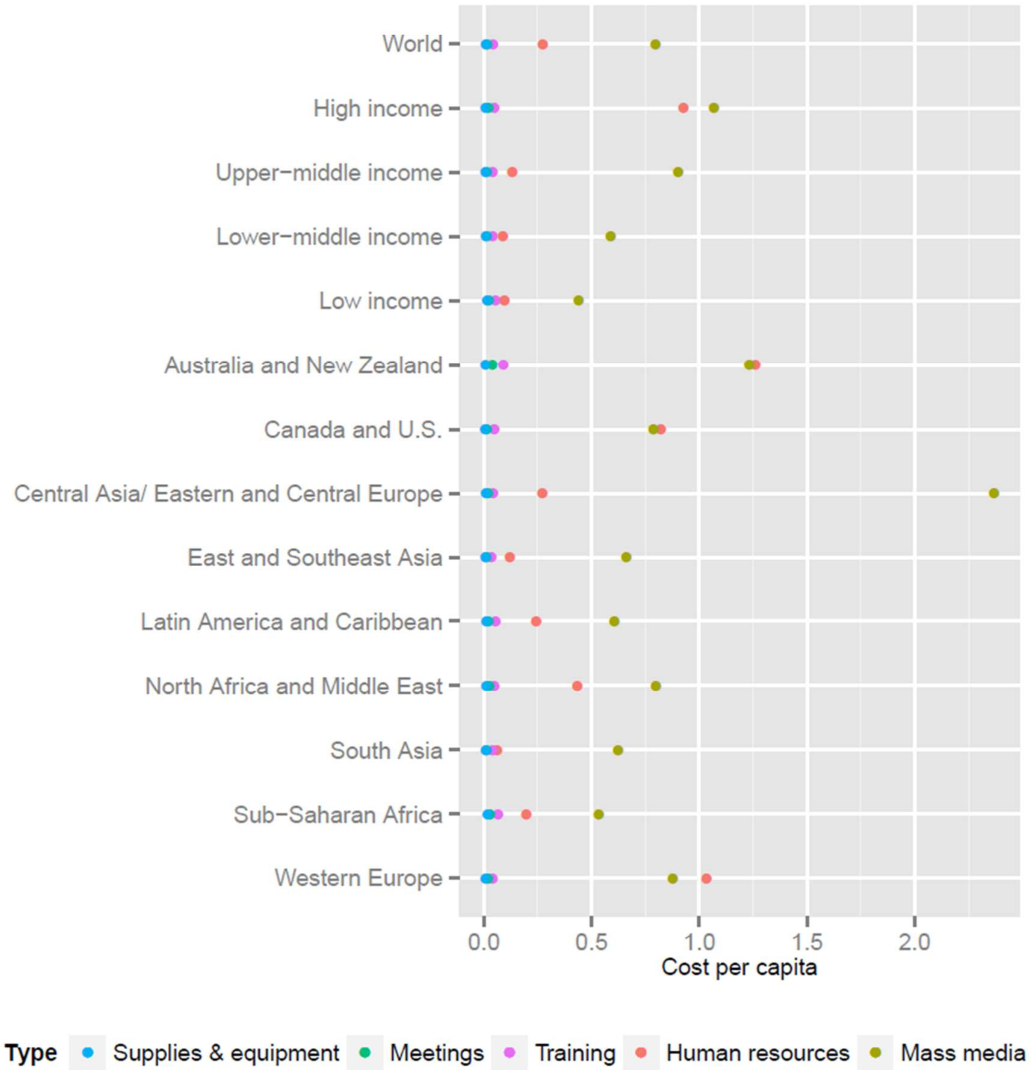
Samoa	169 (97, 246)	$25.42	$11,967.23 ($20,801.04, $8,227.85)	1.93	2.1
Saudi Arabia	52,431 (31,697, 72,979)	$2.13	$576.75 ($954.03, $414.36)	0.02	3.7
Senegal	18,090 (10,986, 25,242)	$0.93	$228.05 ($375.52, $163.43)	0.12	4.1
Serbia	61,318 (39,809, 82,924)	$3.86	$425.77 ($655.82, $314.84)	0.04	9.1
Seychelles	563 (376, 710)	$110.94	$6,109.59 ($9,134.70, $4,844.14)	0.23	18.2
Sierra Leone	12,667 (7,530, 18,338)	$0.98	$171.61 ($288.70, $118.54)	0.12	5.7
Singapore	12,276 (8,210, 16,018)	$5.42	$1,098.18 ($1,641.91, $841.63)	0.02	4.9
Slovakia	38,364 (24,589, 51,641)	$11.67	$1,163.21 ($1,814.85, $864.13)	0.05	10
Slovenia	8,623 (5,582, 11,495)	$5.04	$889.30 ($1,373.82, $667.13)	0.03	5.7
Solomon Islands	1,267 (719, 1,834)	$8.21	$1,416.99 ($2,497.92, $979.24)	0.42	5.8
South Africa	161,479 (96,722, 229,780)	$1.14	$176.06 ($293.93, $123.72)	0.02	6.5
Spain	123,145 (79,960, 166,031)	$1.35	$365.54 ($562.96, $271.12)	0.01	3.7
Sri Lanka	82,979 (54,184, 112,156)	$0.61	$91.72 ($140.47, $67.86)	0.02	6.7
Sudan	45,411 (26,201, 65,790)	$0.50	$193.29 ($335.00, $133.41)	0.08	2.6
Suriname	1,353 (845, 1,906)	$7.01	$1,476.22 ($2,363.86, $1,048.27)	0.12	4.7
Swaziland	4,472 (2,547, 6,372)	$5.59	$543.39 ($954.00, $381.40)	0.1	10.3
Sweden	27,292 (17,394, 37,540)	$2.32	$554.59 ($870.18, $403.21)	0.01	4.2
Switzerland	17,614 (11,068, 23,929)	$2.51	$792.78 ($1,261.71, $583.56)	0.01	3.2
Syrian Arab Republic	74,985 (46,183, 103,790)	$0.75	$86.77 ($140.89, $62.69)	0.02	8.6
Tajikistan	37,292 (24,575, 48,976)	$0.68	$49.95 ($75.79, $38.03)	0.02	13.7
Thailand	270,884 (182,507, 354,029)	$0.33	$54.46 ($80.84, $41.67)	0.01	6.1
Timor-Leste	3,320 (2,183, 4,376)	$6.59	$747.26 ($1,136.38, $566.84)	0.08	8.8
Togo	14,596 (8,554, 20,707)	$0.90	$147.90 ($252.38, $104.26)	0.13	6.1
Tonga	156 (94, 225)	$38.01	$11,176.54 ($18,594.04, $7,738.31)	1.49	3.4
Trinidad and Tobago	5,395 (3,394, 7,481)	$7.17	$1,098.89 ($1,747.11, $792.49)	0.05	6.5
Tunisia	43,888 (28,283, 58,936)	$0.79	$108.90 ($168.99, $81.09)	0.01	7.3
Turkey	339,898 (220,727, 456,923)	$1.62	$194.41 ($299.37, $144.62)	0.01	8.4
Turkmenistan	42,826 (27,919, 56,546)	$3.60	$207.21 ($317.85, $156.93)	0.02	17.4
Uganda	32,885 (17,883, 50,460)	$0.47	$151.08 ($277.83, $98.46)	0.11	3.1
Ukraine	624,510 (402,129, 850,152)	$0.95	$49.72 ($77.21, $36.52)	0.01	19
United Arab Emirates	13,516 (7,447, 20,320)	$3.34	$1,242.39 ($2,254.82, $826.38)	0.03	2.7
United Kingdom	184,120 (116,045, 250,906)	$1.99	$465.59 ($738.71, $341.66)	0.01	4.3
United Republic of Tanzania	58,224 (35,353, 81,234)	$0.53	$146.07 ($240.56, $104.69)	0.09	3.7
United States of America	1,008,472 (660,402, 1,376,241)	$1.65	$332.39 ($507.57, $243.56)	0.01	5
Uruguay	9,291 (5,744, 12,867)	$1.56	$352.45 ($570.06, $254.49)	0.02	4.4
Uzbekistan	208,075 (139,049, 270,194)	$0.41	$26.08 ($39.02, $20.08)	0.01	15.7

Vanuatu	537 (308, 800)	$17.13	$3,187.20 ($5,553.15, $2,140.83)	0.65	5.4
Venezuela (Bolivarian Republic of)	75,782 (48,651, 103,578)	$0.87	$173.33 ($270.00, $126.82)	0.01	5
Viet Nam	246,143 (164,423, 326,144)	$0.31	$62.00 ($92.81, $46.79)	0.02	5
Yemen	54,336 (33,675, 76,059)	$0.72	$107.75 ($173.86, $76.97)	0.05	6.7
Zambia	22,388 (12,953, 32,574)	$0.98	$193.50 ($334.44, $132.99)	0.11	5.1
Zimbabwe	53,126 (32,709, 73,739)	$3.03	$260.33 ($422.83, $187.56)	0.52	11.6

a. Palestine, Somalia, Taiwan, and Sao Tome and Principe could not be included in this analysis due to lack of data.

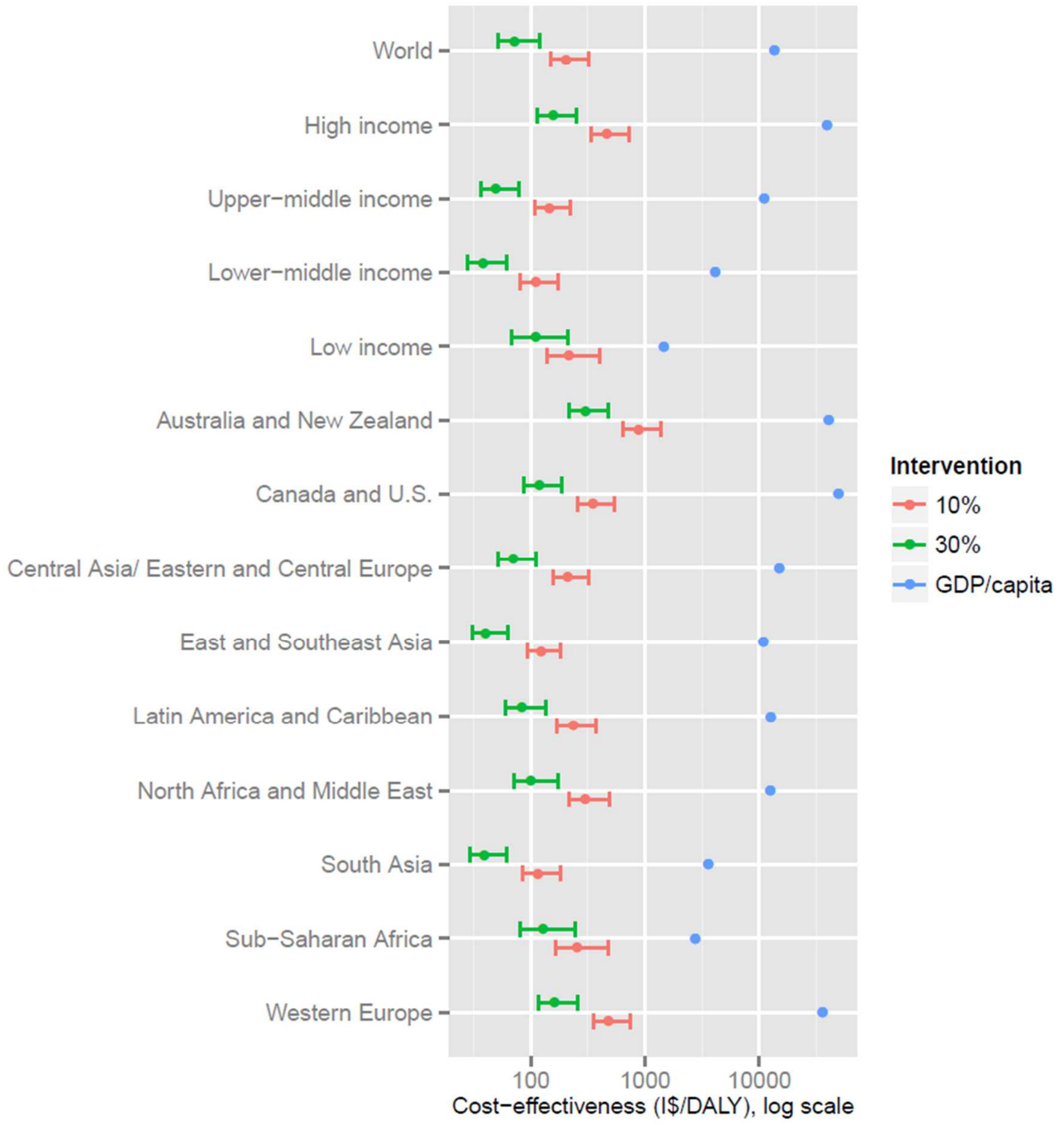
b. The eleven nations with estimated CERs between I$10,000 and I$30,000/DALY were Grenada, Kiribati, Iceland, Brunei, Tonga, Samoa, Qatar, Dominica, the Marshall Islands, Antigua and Barbuda, and Andorra.

eFigure 1. The relative contributions of intervention components to total cost by income and geographic region.



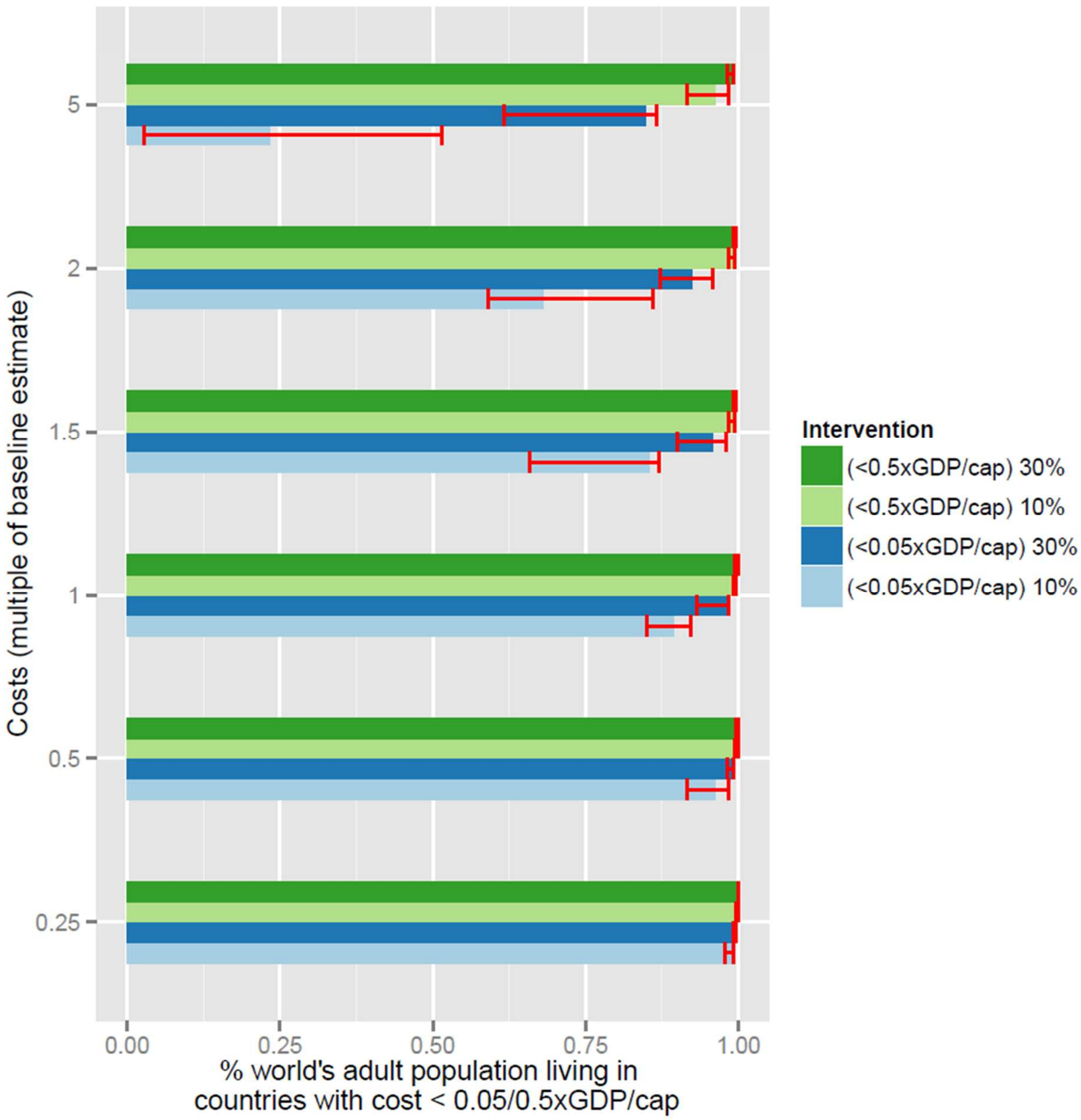
For each income and geographic region, the blue dot shows the cost per capita of supplies and equipment for the intervention, the light green dot the cost per capita of meetings, the pink dot the cost per capita of training, the orange dot the cost per capita of human resources, and the dark green dot the cost per capita of mass media.

eFigure 2. Cost-effectiveness (I$/DALY) by income and geographic region of interventions to reduce sodium consumption by 10% and 30%.



For each income and geographic region, the red point shows the intervention's cost-effectiveness (I$/DALY) and its 95% uncertainty interval assuming an achieved sodium intake reduction of 10%; the green point shows the same assuming a reduction of 30%; and the blue point shows the regional GDP per capita. All figures are population-weighted averages.

eFigure 3. Sensitivity analysis of intervention cost assuming 10% and 30% reductions with optimal intake 2g/day.



For each cost multiple (along the y-axis: 0.25, 0.5, 1, 1.5, 2, and 5 times the baseline cost), the dark and light green lines show the percentage of the world's adult population living in countries with intervention cost <0.5xGDP per capita assuming achieved sodium intake reductions of 30% and 10% respectively; the dark and light blue lines show the percentage of the world's adult population living in countries with intervention cost <0.05xGDP per capita again assuming achieved sodium intake reductions of 30% and 10% respectively.

Population Strategies to Decrease Sodium Intake: A Global Cost-Effectiveness Analysis

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ABSTRACT

Objective. To quantify the cost-effectiveness of a policy intervention to reduce sodium intake in 183 countries worldwide.

Design. We characterized global sodium intakes, blood pressure levels, effects of sodium on blood pressure and of blood pressure on cardiovascular disease, and cardiovascular disease rates in 2010, each by age and sex, in 183 countries. Country-specific costs of a sodium reduction policy were estimated using the World Health Organization Noncommunicable Disease Costing Tool. Country-specific impacts on mortality and disability-adjusted life years (DALYs) were modeled using comparative risk assessment, based on scenarios including 10%, 30%, 0.5 g/d, and 1.5 g/d sodium reductions achieved over 10 years.

Setting and Population. Modeling study in the full adult population in 183 countries.

Intervention. A policy that combines government-supported education and targeted industry agreements to reduce population sodium intake.

Main outcome measures. Cost-effectiveness ratio, evaluated as PPP-adjusted international dollars (I$) per DALY saved over 10 years.

Results. Worldwide, a 10% sodium reduction over 10 years within each country was projected to avert 5,781,000 cardiovascular disease-related DALYs/year, at a population-weighted mean cost of I$1.13 per capita over the 10-year intervention. The population-weighted mean cost-effectiveness ratio was I$204/DALY. Across 21 world regions, estimated cost-effectiveness of sodium reduction was best in South Asia (I$116/DALY); across the world's 30 most populous countries, best in Uzbekistan (I$26.08/DALY) and Myanmar (I$33.30/DALY). Cost-effectiveness was lowest in Australia/New Zealand (I$880/DALY, or 0.02xGDP per capita), although still substantially better than standard thresholds for cost-effective (<3.0xGDP per capita) or highly cost-effective (<1.0xGDP per capita) interventions. Most (96.0%) of the world's adult population lived in countries in which this intervention had a cost-effectiveness ratio <0.1xGDP per capita, and 99.6% in countries with a cost-effectiveness ratio <1.0xGDP per capita.

Conclusion. National education and industry-agreement strategies to reduce dietary sodium are projected to have substantial impacts on cardiovascular disease and be highly cost-effective worldwide.

Funding: National Institutes of Health.

INTRODUCTION

Excessive sodium consumption is common and linked to large health burdens in most countries. 181 of 187 countries, representing 99.2% of the world's adult population, have mean sodium intakes exceeding the World Health Organization (WHO) recommended maximum of 2 g/d.[1] Worldwide, 1,648,000 annual deaths from cardiovascular diseases were attributable to excess dietary sodium in 2010.[2] Accordingly, the 2013 United Nations' Global Action Plan for the Prevention and Control of Noncommunicable Diseases has prioritized sodium reduction as one of 9 key targets for all member nations in 2013-2020.[3]

A potential barrier for implementation of this recommendation is cost. Many countries have limited resources for health-related interventions, requiring careful assessment of their costs and cost-effectiveness. Yet, the potential cost-effectiveness of sodium reduction strategies has been analyzed for only a handful of nations and regions, and in ways that are not generally comparable.[4-12] To address this key gap in knowledge, we assessed the cost-effectiveness of sodium reduction strategies in 183 nations, based on the most up-to-date available data on age- and sex-specific sodium intakes, blood pressure levels, and cardiovascular disease burdens worldwide, the dose-response effects of sodium on blood pressure and of blood pressure on cardiovascular disease, and nation-specific costs for each component of the intervention. Together, these allowed us to model and estimate, using comparable and consistent methods, the cost-effectiveness of sodium reduction strategies for every country.

METHODS

Sodium reduction intervention

We modeled the effects and costs of a 10-year policy intervention to reduce population sodium consumption. The program consisted of government-supported industry targets, similar to the experience in the UK,[13] including: (a) a public health campaign targeting consumer choices, (b) government-supported industry agreements to reduce sodium in processed foods, and (c) government monitoring of industry compliance. We assumed the intervention would scale up linearly over 10 years, with 1/10th of the total sodium reduction in the first year, 2/10th in the second, and so on, reaching full efficacy in the final year. We recognized that an alternative program, such as mandatory regulations, would likely have larger effects, reduce sodium more quickly, and at lower cost, but may be less politically feasible in many countries.

Intervention costs

Country-specific resource needs and costs were derived using the WHO-CHOICE database,[14] which includes detailed component-specific estimates of inputs (ingredients) required for each intervention stage for each country and the estimated unit price for each input in that country (see **eMethods**). To facilitate comparisons between countries, we converted all costs to international dollars ($I) (see **eMethods**), which are based on each nation's purchasing power parity (PPP).[15] One $I in any given country can be interpreted as the funds needed to purchase the same amounts of goods/services in that country as $1US would purchase in the US. We summed costs by year to calculate the total cost of the 10-year intervention for each country, with 3% annual discounting.

In contrast to recent US models,[4, 5] we did not include estimated healthcare savings from prevented cardiovascular disease events because (a) such savings could, in theory, be partly offset by new downstream health events[16, 17] and (b) comparable healthcare costing data is only available for a minority of countries globally. Because including such cost savings would be optimal according to many cost-effectiveness guidelines, our results for overall cost-effectiveness should be considered as a conservative estimate.

Heterogeneity in intervention costs and effectiveness

While the WHO costing framework already accounted for some sources of variation by country in terms of resources required and nation-specific costs, we recognized that details of planning, development, and implementation might further vary from country to country beyond what is captured by the costing tool. We also recognized that achieved effectiveness would vary from country to country. Our base model assumed an average cost of this framework (adjusted for in-country differences in resource use and costs, according to the WHO costing tool), and an average effectiveness. To understand the robustness of our findings to these assumptions, we tested widely varying costs – including variations in resource use and cost of between 0.25 and 5-fold the base – and intervention effectiveness – including 10% and 30% proportional reductions and 0.5 g/d and 1.5 g/d absolute reductions in sodium intake. Ranges of intervention effectiveness were informed by the UK experience, which achieved a 14.7% (1.4 g/d) reduction in population sodium consumption over 10 years,[18] and that of Turkey, which reported a 16% (3 g/d) reduction over 4 years.[19] Together, these findings provided a broad range of possible scenarios against which to evaluate the cost-effectiveness of the intervention.

Intervention impact on disability-adjusted life years (DALYs)

Using data on population demographics, sodium consumption, blood pressure levels, and rates of cardiovascular disease, each in 26 strata by age and sex within each country,[2] we estimated the number of disability-adjusted life years (DALYs) that would be averted by the intervention in each country for each year between 2011 and 2020. Risk reduction in each age-sex-country stratum was calculated from the effect of sodium reduction on systolic blood pressure, including variation in this effect by age, race, and hypertensive status; and the effect of blood pressure reduction on cardiovascular disease, including variation in this effect by age.[2] The final comparative risk assessment model incorporated each of these sources of heterogeneity, as well as their uncertainty. Stratum-specific effects, accounting for underlying demographics and baseline cardiovascular disease rates, were summed to derive national (or regional) effects. See **eMethods** for details on these inputs and their modeling.

While some prior observational studies suggest a J-shaped relation between sodium intake and cardiovascular disease,[20] the potential biases of sodium assessment in observational studies are appreciated (see **eMethods**).[21] In extended follow-up of sodium reduction trials that overcame many of these limitations, linear risk reductions were seen, including to <2300 mg/d.[22] We recognized that while the precise optimal level remains controversial, every major national and international organization that has reviewed all the evidence has concluded that high sodium increases cardiovascular disease risk, and that lowering sodium reduces such risk, with optimal identified intakes ranging from <1200 mg/d to <2400 mg/d.[2] We used an optimal intake of 2000 mg/d (WHO) for our main analysis. For any sodium reductions below this level, we modeled neither additional benefit nor risk, consistent with recent Institute of Medicine conclusions.[23] In sensitivity analyses, we also evaluated lower (1000 mg/d) and higher (3000 mg/d) thresholds for optimal intake.

Our modeling further utilized known strengths of blood pressure as "an exemplar surrogate endpoint for cardiovascular mortality and morbidity."[24] Prospective cohort studies suggest log-linear associations between systolic blood pressure and cardiovascular disease events, down to ~110 mm Hg;[25] and randomized controlled trials indicate that benefits of blood pressure-lowering interventions are largely proportional to the magnitude of blood pressure reduction, rather than the specific intervention, with similar proportional reductions in cardiovascular disease events down to starting blood pressures of ~110 mm Hg.[25-27] In our model, we assumed a log-linear dose-response between blood pressure and cardiovascular disease until a systolic blood pressure level of 115 mm Hg, after which we assumed no further lowering of risk. Given the relatively rapid reductions in cardiovascular disease events in randomized trials of blood pressure-lowering therapies, and the prolonged period of our intervention (10 years), we did not model any lag and assumed concurrent gradual benefits in both blood pressure reduction and cardiovascular disease.

Cost-effectiveness ratios

To calculate the cost-effectiveness ratio for each country, we divided the total effect on DALYs by the total cost of the intervention over 10 years. We compared these cost-effectiveness ratios to WHO benchmarks, which define a cost-effectiveness ratio <3xGDP per capita as cost-effective, and <1xGDP per capita as highly cost-effective.[28] We appreciated the potential limitations of these WHO benchmarks,[29] yet also their practicality for multi-national studies such as this. To quantify statistical uncertainty, we used probabilistic sensitivity analyses based on 1,000 Monte Carlo simulations to derive 95% uncertainty intervals, with varying inputs for sodium exposure, blood pressure levels, effects of sodium on blood pressure, and effects of blood pressure on cardiovascular disease (see **eMethods**).

Role of the funding source

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in developing plans for design or implementation of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of the research to study participants or the relevant patient community.

RESULTS

Cost-effectiveness of sodium reduction by national income level and region

The population characteristics and estimated costs, DALYs saved, and overall cost-effectiveness of a policy intervention to reduce sodium, based on a 10% reduction in population sodium, are shown globally, by national income, and by geographic region (**Table 1)**. Worldwide, over 10 years, the intervention averted an estimated 5.78 million cardiovascular disease-related DALYs/year (95% uncertainty interval (UI) 3.83 to 7.65). Nearly half (42.0%, 2,426,749/5,781,193) of averted DALYs were attributable to coronary heart disease (CHD), a similar proportion (40.1%, 2,318,402/5,781,193) to stroke, and the remainder (17.9%, 1,036,042/5,781,193) to other cardiovascular disease. Overall, a 10% sodium reduction would reduce the total burden of cardiovascular disease worldwide by 1.96% (5,781,193/295,035,800). Per 1,000 adults globally, 1.51 DALYs on average would be averted annually (95%UI 1.01 to 2.00), with larger impact in upper-middle-income countries (1.74 DALYs, 95%UI 1.15 to 2.28) than high-income countries (1.04 DALYs, 95%UI 0.68 to 1.40). Among 9 world regions, largest estimated reductions in DALYs would be in Central Asia/Eastern and Central Europe (3.46 DALYs per 1,000 people per year, 95%UI 2.26 to 4.56); although even regions with smallest effects would experience benefits (e.g., Australia/New Zealand: 0.66 DALYs, 95%UI 0.42 to 0.89).

Even with PPP-correction, the estimated intervention costs per capita generally decreased with higher country income, although not uniformly. Per capita, the average estimated 10-year cost in high-income nations (I$2.07) was nearly double that in upper-middle-income countries (I$1.09), with smaller differences between lower-middle-income (I$0.74) and low-income (I$0.62) countries (**Table 1**). By world region, per capita cost was highest in Central Asia/Eastern and Central Europe (I$2.71) and Australia/New Zealand (I$2.63). Estimated intervention costs in South Asia (I$0.74), Sub-Saharan Africa (I$0.83), East/Southeast Asia (I$0.83), and Latin America/Caribbean (I$0.93) were each below a dollar per capita.

The relative contributions of each intervention component to the total 10-year cost differed significantly between countries (**eFigure 1**). For instance, costs of supplies/equipment, meetings, and training were uniformly low (averaging I$0.01, I$0.01, and I$0.04 per capita respectively), whereas costs of human resources and mass media were much higher and more variable across countries. Globally, average PPP-adjusted costs for human resources (personnel salaries) were I$0.27 per capita, but with a 9-fold range comparing high-income (I$0.93) to low-income (I$0.10) countries. Human resources were most costly in Australia/New Zealand (I$1.26 per capita), Western Europe (I$1.03), and Canada/US (I$0.82); and lowest in South Asia (I$0.06). Mass media costs were generally the most expensive component of the intervention: I$0.80 per capita globally, I$1.07 for high-income nations, and I$0.44 for low-income nations. They represented the most costly component of the intervention in every region except for Australia/New Zealand, Canada/US, and Western Europe, where human resources was the most costly component.

Globally, the estimated average cost-effectiveness ratio of the 10-year intervention was I$204 per DALY saved (95%UI 149 to 322). This did not include potential savings from lower health care costs or higher productivity due to averted cardiovascular disease events, which would each further improve the estimated cost-effectiveness. The estimated cost-effectiveness ratio was lowest (best) in lower-middle-income countries (I$111, 95%UI 81 to 175) and upper-middle-income countries (I$146, 95%UI 109 to 223); higher in low-income countries (I$215, 95%UI 139 to 400); and highest in high-income countries (I$465, 95%UI 341 to 724). By region, lowest cost-effectiveness ratios were in South Asia and East/Southeast Asia (I$116 and I$123, respectively). In Central Asia/Eastern and Central Europe, high intervention efficacy partly offset its higher projected cost, generating the next best cost-effectiveness ratio (I$211, 95%UI 157 to 324).

Effectiveness, cost, and cost-effectiveness by country

Across individual countries, the estimated intervention efficacy, in terms of DALYs averted per 1,000 people, was highest in Kazakhstan (23.0, 95%UI 15.6 to 29.8), Georgia (21.6, 95%UI 14.3 to 28.3), Belarus (19.8, 95%UI 12.8 to 26.9), Ukraine (19.0, 95%UI 12.3 to 25.9), Mongolia (18.9, 95%UI 12.1 to 25.0), and Russia (18.8, 95%UI 12.2 to 25.5) (**eTable 2**). The relative rankings of these nations should be considered in the context of the uncertainty in the estimates that preclude, for example, confirming statistically significant differences in efficacy between Kazakhstan and Russia. Nonetheless, the range of estimated efficacy across the 183 nations was large, for example lowest in

Jamaica (1.9, 95%UI 1.1 to 2.7), Qatar (1.4, 95%UI 0.8 to 1.9), Rwanda (1.3, 95%UI 0.6 to 2.3), and Kenya (0.4, 95%UI 0.2 to 0.7).

Per capita, estimated 10-year intervention cost was lowest in Myanmar, Vietnam, DPR Korea (each I$0.31), Thailand (I$0.33), Nepal (I$0.40), and Uzbekistan (I$0.41) (**eTable 2**). A total of 68 countries had estimated 10-year intervention costs<I$1.00 per capita. For 84 countries, estimated costs were between I$1.00 and I$9.99; for 19 countries, between I$10 and I$29.99; and for 12, greater than I$30.

Estimated national cost-effectiveness ratios were correspondingly variable (**Figure 1**). Uzbekistan's was lowest (best) at I$26.08/DALY (95%UI 20.08 to 39.02), followed by Myanmar (I$33.30, 95%UI 25.10 to 50.46). 28 countries had estimated cost-effectiveness ratios below I$100/DALY, and 112 more, below I$1000/DALY. Eleven nations, all very small, had estimated cost-effectiveness ratios between I$10,000 and I$30,000/DALY (**eTable 2**).

WHO benchmarks for cost-effectiveness

In comparison to WHO benchmarks (cost-effectiveness ratio <3xGDP/capita is cost-effective, <1xGDP/capita, highly cost-effective),[28] the 10-year sodium reduction intervention was estimated to be highly cost-effective globally. Across all 183 countries, the estimated cost-effectiveness ratio of this policy intervention was >3xGDP/capita in only one nation (Marshall Islands: 4.7xGDP/capita), between 3 and 1xGDP/capita in six nations (Kenya, Tonga, Kiribati, Samoa, Micronesia, Comoros), and highly cost-effective in all other nations (**Figure 2**). Indeed, in 130 countries, representing more than 96% of the world's population, the estimated cost-effectiveness ratio was <0.1xGDP/capita, far below usual cost-effectiveness thresholds. This included each of the world's 20 most populous countries (**Figure 3)**.

Potential heterogeneity of effectiveness and costs

Sodium reduction remained highly cost-effective globally and by world region when we considered alternative effectiveness (proportional reduction of 30%, absolute reduction of 0.5 g/d or 1.5 g/d); and alternative thresholds of optimal intake (the level at which further sodium reduction produces no further health benefits) of 3.0 or 1.0 g/d (**Table 2**). Generally, achieving larger sodium reduction targets (e.g., 30%, 1.5 g/d) was more cost-effective (**eFigure 2**), but even modest achieved reductions (10% or 0.5 g/d over 10 years) were highly cost-effective. Under any of these scenarios, the estimated cost-effectiveness ratio was <0.05xGDP/capita in every world region except Sub-Saharan Africa. Due to generally low sodium intakes in that region, the estimated cost-effectiveness ratio was <0.1xGDP/capita when the optimal intake threshold was 1.0 g/d or 2.0 g/d, but up to 6.0xGDP/capita when it was assumed to be 3.0 g/d.

As expected, cost-effectiveness ratios were sensitive to variations in estimated intervention cost. We evaluated the proportion of the world's adult population living in countries with a cost-effectiveness ratio (I$/DALY) <0.05x and <0.5xGDP/capita, for varying intervention costs that were 25%, 50%, 150%, 200%, or 500% of baseline cost estimates **(eFigure 3**). For a 10% sodium reduction, under the base scenario for cost estimates, 89% of the global adult population would live in countries with a cost-effectiveness ratio <0.05xGDP/capita. This decreased to 23% of the global adult population if costs were 5-fold higher, 68% if costs were 2-fold higher, and 85% if costs were 1.5-fold higher; while it increased to 96% if costs were half as large, and 99% if costs were one quarter as large. For a 30% sodium reduction, the corresponding figures for a benchmark of <0.05xGDP/capita were 85%, 92%, 96%, 98%, 99.1%, and 99.3% of the global adult population. We also made comparisons against a cost-effectiveness ratio benchmark <0.5xGDP/capita, still substantially below the WHO criterion of 1xGDP as highly cost-effective. For a 10% sodium reduction, even if the intervention costs were 5-fold greater than the baseline estimate, 96% of the world's population would live in countries with a cost-effectiveness ratio <0.5xGDP/capita; and for a 30% sodium reduction, 99% would.

DISCUSSION

Principal findings

We found that a national policy intervention to reduce population sodium consumption by 10% over 10 years was projected to be highly cost-effective (<1xGDP/capita per DALY saved) in nearly every country in the world, and remarkably cost-effective (<0.05xGDP/capita per DALY) in the great majority of countries. Hundreds of thousands of deaths, and millions of DALYs, were estimated to be averted annually, at low cost.

Comparison with other prevention strategies

These cost-effectiveness ratios compare very favorably with other prevention strategies. For example, 'best buy' pharmacologic interventions to reduce cardiovascular disease in high-income countries have estimated cost-effectiveness ratios >$21,000/DALY for primary prevention (statins) and >$6,000/DALY for secondary prevention (beta-blockers).[30, 31] By contrast, we project a cost-effectiveness ratio of I$465/DALY for the 10% sodium reduction intervention in high-income countries. Similarly, our projected cost-effectiveness ratio of I$143/DALY in low- and middle-income countries compares very favorably with an estimated cost-effectiveness ratio of I$900/DALY for a cardiovascular disease combination pill ('polypill') targeted at high-risk individuals in developing countries.[32]

Notably, several of these prior pharmacologic cost-effectiveness ratios incorporated estimated health savings from averted cardiovascular disease events, which produces substantially lower cost-effectiveness ratios than if estimated health savings are omitted, as in our analysis.[31, 32] Prior cost-effectiveness analyses of potential sodium reduction programs in specific countries, such as the US, suggest actual cost-savings when healthcare costs are included.[4-6, 8, 9] In our analysis, inclusion of savings from averted events would have produced even greater cost-effectiveness or even cost-savings from a health sector perspective. From a wider societal perspective, further potential savings (e.g., from reductions in productivity losses) might make sodium reduction interventions even more attractive.

Our investigation builds upon and substantially extends prior analyses of potential sodium reduction interventions in several important respects. First, most included only a single high-income nation.[4-6, 9] One prior analysis included 23 more varied nations, but only estimated averted deaths, rather than DALYs,[12] preventing comparison with other cost-effectiveness ratios. In contrast to prior analyses, we also jointly incorporated heterogeneity in blood pressure effects of sodium reduction by age, race, and hypertensive status, providing more accurate cardiovascular disease impact estimates. Additionally, our analysis of 183 countries using consistent methods enabled us to explore sources of heterogeneity and sensitivity in estimated cost-effectiveness across nations and regions.

Sources of heterogeneity

Differences in intervention costs were one of the major drivers of varying cost-effectiveness ratios. The large variation of human resource and mass media costs across countries suggests potential savings from multinational efforts to reduce sodium, which could benefit from economies of scale. For instance, the new European Union Salt Reduction Framework, which monitors national sodium reduction initiatives and supports implementation efforts across multiple member nations,[33] could be emulated elsewhere. Consistent with the relevance of scale, the 20 nations with highest per capita intervention costs all had adult populations <500,000. In addition, the higher cost of mass media, compared to other intervention components, suggests a need for further research on how best to target such resources. The recent finding[34] that salt reduction in the UK has arisen from product reformulation rather than changes in consumer choice suggests that, in countries where most dietary sodium comes from processed food (e.g., 77% in the US[35]), an intervention consisting of industry targets but without mass media components might be more cost-effective. Nevertheless, even with an up to 20-fold variation in PPP-adjusted total costs, our multi-national investigation suggests that a government-supported sodium reduction program would be highly cost-effective for nearly every country in the world.

Our findings were robust to differing thresholds for optimal sodium intake. While the precise optimal level of sodium intake remains uncertain,[23] to our knowledge ours is the first cost-effectiveness analysis to evaluate the relevance of this uncertainty to policy. We found that this threshold influences relative cost-effectiveness only in countries with the lowest intakes, with very little effect in most others. For example, cost-effectiveness ratios increase notably in Sub-Saharan Africa when the threshold is raised from 2.0 to 3.0 g/d, but relatively little in most other nations (**Table 2**).

Strengths and limitations

While our analysis has several strengths (see **eDiscussion**), potential limitations should be considered. We utilized estimates of sodium consumption, blood pressure levels, and rates of cardiovascular disease based on raw data covering a majority but not all of the global population, with hierarchical estimation of the remainder.[1, 36, 37] Our estimates of health benefits accounted only for cardiovascular disease, whereas high sodium intake is also associated with vascular stiffness, renal dysfunction, and stomach cancer, independent of blood pressure levels.[38-40] We did not account for possible unintended consequences of the intervention, such as changes in population choices of overall foods consumed. We did not model health system savings from averted cardiovascular disease events. Averting events may compress disease and costs later in life, reducing overall morbidity and lifetime costs, but modeling all potential subsequent health transitions and treatment costs for every nation globally is not yet feasible. Our models are based on a 10-year intervention period including planning, development, and staged implementation. Over the longer-term, intervention costs may decrease, while lifetime health benefits might also increase. Thus, these findings should be considered a platform on which to base intermediate-term policies, recognizing that longer-term effectiveness should also be evaluated. We did not evaluate other potential interventions to reduce sodium, such as mandatory quality standards or taxation, which might be more effective and less costly, although less feasible in certain nations.

Conclusions

In summary, we found that a government-supported, voluntary, coordinated national policy to reduce population sodium consumption by 10% over 10 years would be extremely cost-effective in nearly all of 183 nations evaluated.

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Contributors:

MW and DM conceptualised the study and wrote the final draft of the paper; DM also provided funding support and supervision. MW undertook the analysis, and wrote the first draft of the paper. SF, GMS, SK, and RM prepared data and commented on the paper. JP commented on the paper. All authors approved the final version. MW acts as guarantor of the study.

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Competing interests:

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: financial support from the National Institutes of Health for the submitted work. Dr. Mozaffarian reports ad hoc honoraria or consulting from Boston Heart Diagnostics, Haas Avocado Board, Astra Zeneca, GOED, DSM, and Life Sciences Research Organization, none of which were related to topics of dietary sodium. The other authors report no financial relationships with any organisations that might have an interest in the submitted work in the previous three years.

Ethical approval: Not required.

Data sharing: The global data on sodium intake may be requested from the authors for academic collaborations; see http://www.globaldietarydatabase.org/requesting-data.html. Global data on blood pressure is available for download at https://www1.imperial.ac.uk/publichealth/departments/ebs/projects/eresh/majidezzati/healthmetrics/metabolicriskfactors/metabolic_risk_factor_maps/ Global data on cardiovascular events is available for download from the Global Burden of Diseases Study at http://ghdx.healthdata.org/global-burden-disease-study-2013-gbd-2013-data-downloads

The lead author (MW) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

SUMMARY BOX

What is already known on this topic

- In prior research in a limited number of high-income nations, national policies to reduce excess sodium intake have been estimated to be highly cost-effective for reducing hypertension and cardiovascular disease.
- For most countries of the world, the cost-effectiveness of a national policy intervention to reduce sodium is unknown.

What this study adds

- We found that a government-supported, voluntary, coordinated national policy to reduce population sodium consumption by 10% over 10 years would be extremely cost-effective in nearly all of 183 nations evaluated, with an average cost-effectiveness ratio (not accounting for potential health care savings due to averted events) of I$204/DALY.

PRINT ABSTRACT

Study question. To quantify the cost-effectiveness of a policy intervention to reduce sodium intake in 183 countries worldwide.

Methods. We characterized global sodium intakes, blood pressure levels, effects of sodium on blood pressure and of blood pressure on cardiovascular disease, and cardiovascular disease rates in 2010, each by age and sex, in 183 countries. Country-specific costs of a policy that combines government-supported education and targeted industry agreements to reduce population sodium intake were estimated using the World Health Organization Noncommunicable Disease Costing Tool. Country-specific impacts on mortality and disability-adjusted life years (DALYs) were modeled using comparative risk assessment, based on scenarios including 10%, 30%, 0.5 g/d, and 1.5 g/d sodium reductions achieved over 10 years. Cost-effectiveness was evaluated as PPP-adjusted international dollars (I$) per DALY saved over 10 years.

Study answer and limitations. Worldwide, a 10% sodium reduction over 10 years within each country was projected to avert 5,781,000 cardiovascular disease-related DALYs/year, at a mean cost of I$1.13 per capita over the 10-year intervention and with a cost-effectiveness ratio of I$204/DALY. We did not account for possible unintended consequences of the intervention, nor model health system savings from averted cardiovascular disease events.

What this study adds. We found that a government-supported, voluntary, coordinated national policy to reduce population sodium consumption by 10% over 10 years would be extremely cost-effective in nearly all of 183 nations evaluated.

Funding, competing interests, data sharing This research was supported by the National Institutes of Health. Dr. Mozaffarian reports ad hoc honoraria or consulting from Boston Heart Diagnostics, Haas Avocado Board, Astra Zeneca, GOED, DSM, and Life Sciences Research Organization, none of which were related to topics of dietary sodium. The other authors report no financial relationships

with any organisations that might have an interest in the submitted work in the previous three years.

The global data on sodium intake, blood pressure, and cardiovascular events are all available for download.

Suggested figure: Fig 1.

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FIGURE LEGENDS

Figure 1. Cost-effectiveness (I$/DALY) by country of an intervention to reduce sodium consumption by 10%.

Figure 2. Cost-effectiveness (I$/DALY as a multiple of GDP per capita) by country of an intervention to reduce sodium consumption by 10%.

Figure 3. Affordability of an intervention to reduce sodium reduction by 10% in the world's 20 most populous countries. Each point shows the cost-effectiveness of the intervention (I$/DALY) for a given country against that country's GDP per capita (I$). The dotted lines show 0.01x, 0.05x, and 0.1xGDP per capita. So, for example, Nigeria and Bangladesh, being to the right of the black line and to the left of the red line, have a cost-effectiveness ratio less than 0.1xGDP per capita but greater than 0.05xGDP per capita.

Table 1. Cost-effectiveness by income and geographic region of a government-supported policy intervention to reduce sodium consumption by 10%.[a]

	Population characteristics			**Costs (10-year total)**		**Total DALYs averted per year (average)**				**10-year interventio n**
	Adult populatio n, millions	**Sodium, g/day (95% UI)**	**SBP, mmHg (95% UI)**	**Interventio n cost/capita, I$**	**GDP/capit a, I$**	**All CVD (95% UI)**	**CHD[b] (95% UI)**	**Stroke (95% UI)**	**Other CVD (95% UI)**	**I$/DALY (95% UI)**
	Total	*Weighted avg.*	*Weighted avg.*	*Weighted avg.*	*Weighted avg.*	*Total*	*Total*	*Total*	*Total*	*Weighted avg.*
World[c]	3,818	4.0 (3.5 to 4.4)	126 (121 to 132)	1.13	13,529	5,781,193 (3,839,910 to 7,649,940)	2,426,749 (1,592,687 to 3,251,879)	2,318,402 (1,560,469 to 3,035,231)	1,036,042 (688,446 to 1,368,222)	204 (149 to 322)
High income[d]	755	4.0 (3.6 to 4.3)	127 (122 to 133)	2.07	38,818	783,883 (510,386 to 1,054,176)	396,007 (259,797 to 534,578)	222,376 (146,908 to 295,486)	165,500 (107,651 to 221,276)	465 (341 to 724)
Upper-middle income	1,528	4.4 (4.0 to 4.8)	127 (122 to 132)	1.09	11,001	2,660,459 (1,763,649 to 3,486,628)	1,003,729 (652,361 to 1,333,710)	1,237,874 (838,534 to 1,617,955)	418,856 (280,732 to 547,912)	146 (109 to 223)
Lower-middle income	1,212	3.7 (3.3 to 4.3)	124 (119 to 130)	0.74	4,100	1,940,077 (1,267,576 to 2,587,018)	902,273 (578,668 to 1,217,060)	679,192 (451,077 to 905,715)	358,612 (234,396 to 476,896)	111 (81 to 175)
Low income	323	3.1 (2.3 to 3.8)	126 (118 to 135)	0.62	1,456	396,773 (269,537 to 527,676)	124,739 (84,056 to 166,821)	178,959 (121,972 to 236,400)	93,075 (62,353 to 124,737)	215 (139 to 400)
Australia and New Zealand	17	3.4 (3.3 to 3.7)	124 (117 to 131)	2.63	40,181	11,254 (7,189 to 15,198)	6,659 (4,217 to 9,081)	2,495 (1,588 to 3,357)	2,100 (1,333 to 2,876)	880 (646 to 1382)
Canada and U.S.	226	3.6 (3.4 to 3.8)	123 (118 to 127)	1.67	48,940	238,357 (156,342 to 326,196)	136,604 (88,092 to 189,180)	48,032 (31,392 to 64,965)	53,721 (34,784 to 72,166)	350 (257 to 537)
Central Asia/ Eastern and	273	4.3 (3.6 to 5.0)	133 (126 to	2.71	14,833	944,059 (615,884 to	530,472 (347,931 to	307,475 (204,004 to	106,112 (69,804 to	211 (157 to

Central Europe			140)			1,245,547)	707,931)	403,720)	140,615)	324)
East and Southeast Asia	1,354	4.6 (4.3 to 5.1)	126 (121 to 130)	0.83	10,777	2,139,880 (1,428,092 to 2,809,299)	617,817 (405,227 to 826,603)	1,176,978 (793,689 to 1,535,809)	345,084 (230,836 to 449,547)	123 (93 to 184)
Latin America and Caribbean	316	3.5 (3.1 to 3.9)	126 (120 to 133)	0.93	12,505	325,607 (212,912 to 437,512)	140,529 (90,822 to 191,668)	110,632 (72,322 to 146,709)	74,446 (48,485 to 99,236)	236 (171 to 375)
North Africa and Middle East	225	3.9 (3.3 to 4.7)	125 (118 to 131)	1.31	12,436	367,829 (235,762 to 498,060)	171,883 (109,403 to 233,374)	112,826 (72,727 to 152,981)	83,120 (53,259 to 111,970)	300 (215 to 490)
South Asia	786	3.7 (3.4 to 4.1)	123 (117 to 128)	0.74	3,551	1,136,614 (733,267 to 1,534,026)	582,096 (364,382 to 791,879)	331,062 (218,435 to 444,645)	223,456 (143,221 to 299,264)	116 (85 to 182)
Sub-Saharan Africa	320	2.5 (2.0 to 3.0)	130 (123 to 137)	0.83	2,743	335,053 (202,998 to 468,036)	95,140 (58,076 to 133,355)	156,910 (95,447 to 218,782)	83,003 (50,151 to 116,135)	255 (166 to 473)
Western Europe	301	3.8 (3.5 to 4.3)	130 (124 to 136)	1.98	35,676	282,541 (183,440 to 380,484)	145,548 (94,348 to 196,380)	71,992 (46,942 to 96,720)	65,000 (41,894 to 87,414)	477 (350 to 744)

a. A program of government-supported industry targets including: (a) a public health campaign targeting consumer choices, (b) government-supported industry agreements to reduce sodium in processed foods, and (c) government monitoring of industry compliance. These results reflect the total effect over a 10-year policy intervention that includes 4 stages: planning (year 1), development (year 2), partial implementation (years 3-5), and full implementation (years 6-10).

b. CHD is coronary heart disease; stroke is ischemic stroke and hemorrhagic and other non-ischemic stroke; other CVD is aortic aneurysm, atrial fibrillation and flutter, cardiomyopathy and myocarditis, endocarditis, hypertensive heart disease, peripheral vascular disease, rheumatic heart disease, and other cardiovascular and circulatory diseases.

c. In 2010 globally, the total burden of cardiovascular disease (CVD) was 295,035,800 DALYs, of which CHD accounted for 129,819,900 DALYs, stroke 102,232,300 DALYs, and other CVD 62,983,600 DALYs. There were 14,669,000 total CVD deaths, of which 6,963,000 were CHD deaths, 5,798,000 stroke deaths, and 1,909,000 other CVD deaths. The numbers of deaths in each subtype may not exactly sum to the total CVD deaths due to rounding.

d. Income categorizations based on the World Bank classification system (http://data.worldbank.org/about/country-classifications/country-and-lending-groups).

Table 2. Variation in cost-effectiveness depending on heterogeneity of both intervention efficacy and optimal level of sodium intake by income and geographic region.[a]

			Cost-effectiveness (I$/DALY)											
			Optimal sodium intake = 1.0 g/d				Optimal sodium intake = 2.0 g/d				Optimal sodium intake = 3.0 g/d			
	Intervention cost/capita, I$	**GDP/capita, I$**	**10%**	**30%**	**0.5g**	**1.5g**	**10%**	**30%**	**0.5g**	**1.5g**	**10%**	**30%**	**0.5g**	**1.5g**
World	1.13	13,553	202 (155 to 307)	66 (50 to 102)	158 (121 to 241)	51 (39 to 78)	204 (149 to 322)	72 (52 to 119)	160 (117 to 251)	60 (43 to 99)	7572 (1549 to 238812)	7217 (1174 to 219444)	14013 (1401 to 228971)	3952 (1527 to 221668)
High income[b]	2.03	38,818	480 (365 to 731)	156 (118 to 242)	378 (288 to 583)	122 (93 to 188)	465 (341 to 724)	156 (114 to 251)	369 (270 to 573)	126 (92 to 199)	511 (371 to 831)	198 (140 to 327)	410 (291 to 693)	176 (125 to 292)
Upper-middle income	1.06	11,001	150 (117 to 224)	49 (37 to 74)	127 (99 to 190)	41 (32 to 61)	146 (109 to 223)	49 (37 to 78)	123 (92 to 186)	44 (32 to 67)	192 (133 to 346)	89 (57 to 185)	162 (110 to 319)	85 (55 to 194)
Lower-middle income	0.72	4,115	113 (86 to 174)	37 (28 to 58)	82 (63 to 125)	26 (20 to 41)	111 (81 to 175)	38 (28 to 61)	81 (59 to 127)	30 (21 to 48)	150 (101 to 271)	68 (43 to 138)	113 (75 to 217)	63 (40 to 130)
Low income	0.80	1,456	130 (97 to 207)	43 (32 to 69)	75 (56 to 117)	27 (20 to 44)	215 (139 to 400)	110 (68 to 212)	142 (93 to 266)	101 (61 to 208)	87264 (16506 to 2832119)	84582 (13187 to 2604509)	164290 (15143 to 2715885)	48004 (17437 to 2630998)
Australia and New Zealand	2.63	40,181	891 (675 to 1358)	292 (218 to 451)	622 (465 to 954)	203 (152 to 315)	880 (646 to 1382)	300 (215 to 477)	621 (455 to 955)	221 (159 to 344)	1037 (755 to 1675)	427 (305 to 691)	753 (538 to 1238)	374 (269 to 586)
Canada and U.S.	1.67	48,940	361 (275 to 543)	118 (89 to 178)	264 (201 to 405)	86 (65 to 132)	350 (257 to 537)	118 (87 to 187)	259 (190 to 399)	89 (66 to 138)	389 (287 to 616)	153 (111 to 245)	294 (210 to 483)	133 (96 to 212)

Central Asia/ Eastern and Central Europe	2.59	14,833	220 (170 to 330)	72 (54 to 109)	185 (143 to 279)	60 (46 to 90)	211 (157 to 324)	70 (52 to 112)	179 (133 to 270)	60 (44 to 91)	220 (161 to 349)	81 (58 to 129)	188 (136 to 308)	73 (53 to 117)
East and Southeast Asia	0.82	10,777	130 (102 to 190)	42 (33 to 62)	124 (97 to 183)	40 (31 to 59)	123 (93 to 184)	40 (31 to 63)	118 (89 to 174)	39 (29 to 59)	129 (94 to 214)	48 (33 to 87)	122 (88 to 209)	47 (33 to 88)
Latin America and Caribbean	0.87	12,505	233 (176 to 358)	76 (57 to 120)	151 (116 to 235)	50 (37 to 77)	236 (171 to 375)	83 (60 to 137)	157 (114 to 249)	64 (46 to 104)	415 (271 to 795)	228 (136 to 504)	309 (196 to 705)	217 (130 to 549)
North Africa and Middle East	1.33	12,436	314 (234 to 501)	102 (76 to 167)	253 (190 to 409)	81 (60 to 130)	300 (215 to 490)	100 (71 to 173)	245 (177 to 406)	84 (59 to 139)	325 (227 to 563)	123 (83 to 216)	268 (184 to 482)	111 (76 to 196)
South Asia	0.74	3,551	121 (92 to 187)	40 (30 to 61)	91 (70 to 140)	29 (22 to 45)	116 (85 to 182)	39 (29 to 62)	88 (65 to 138)	30 (22 to 48)	126 (91 to 205)	49 (34 to 79)	98 (69 to 167)	42 (30 to 70)
Sub-Saharan Africa	1.01	2,769	161 (120 to 256)	53 (39 to 85)	80 (59 to 122)	30 (22 to 48)	255 (166 to 473)	127 (80 to 242)	155 (101 to 289)	115 (70 to 236)	88269 (16762 to 2859366)	85502 (13376 to 2629504)	165968 (15351 to 2741935)	48337 (17666 to 2656245)
Western Europe	2.00	35,676	489 (371 to 742)	160 (120 to 246)	374 (283 to 573)	121 (92 to 186)	477 (350 to 744)	160 (118 to 256)	367 (268 to 565)	126 (92 to 197)	528 (387 to 845)	205 (146 to 329)	412 (294 to 687)	180 (128 to 288)

a. A sodium reduction intervention may have differing effectiveness in different settings. To test the robustness of findings to different assumptions, we evaluated varying intervention effectiveness – including 10% and 30% proportional reductions and 0.5 g/d and 1.5 g/d absolute reductions in sodium intake. In addition, the optimal level of sodium intake remains uncertain. We evaluated 1.0, 2.0, and 3.0 g/d as varying optimal levels of sodium intake: the threshold at which further reductions in intake lead to no further cardiovascular disease benefits.

b. Income categorizations based on the World Bank classification system (http://data.worldbank.org/about/country-classifications/country-and-lending-groups).