BI CENTER FOR CLIMATE STRATEGY

Review of our Plans for the World 4 (PEEC) Model

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Framework conditions of our work

Based on thinking / work of
2052 – A Global Forecast for the Next Forty Years

We want to analyze policies that have been proposed to solve global problems of
— resource scarcity,
— environmental damage,
— climate change,
— biodiversity loss,
— unemployment and
— inequity.

Public domain

Most likely the resulting book will be a report to the Club of Rome

We want to test unconventional, but politically feasible, solutions I

It is possible to …

…generate higher <u>well-being</u> in the future by shifting global investment flows away from cost-effective solutions towards more costly solutions – for example by shifting labour and capital from cheap (and dirty) to more costly (and clean) production.

…generate sustainable growth in GDP and employment by increasing the tax level – for example by taking from the rich and giving to the poor.

…generate sustainable growth in GDP and employment by printing fresh money and use to pay for green activity – often called green stimulus packages.

…reduce unemployment by shortening the length of the work year in full time jobs.

…solve the problems of increasing dependency ratio by increasing the pension age.

We want to test unconventional, but politically feasible, solutions II

It is true that …

…the main effect of growing resource scarcity (that is, depletion of cheaply accessible resources) is reduced consumption growth. Resource scarcity does *not* lead to reduced growth in GDP nor to higher unemployment.

…the main effect of accelerated climate action – that is, accelerated reduction of man-made greenhouse gas emissions – is reduced consumption growth. Strong climate action does *not* lead to reduced growth in GDP nor to higher unemployment.

…the global capacity to produce electricity, heat, and food exceeds by far the amounts that will be demanded before 2100.

System boundary

Time horizon: 1970 - 2100

As LtG but with
Real economy (much revamped)
Financial economy

Population divided into
Owners
Workers

World divided into
Rich nations
Poor nations
maybe 5 regions as in 2052

Sectors
(World) populations
Production (GDP)
Energy use
GHG emissions
Climate effects
Resource flows
Food production
Other emissions
Investment allocation

Basic mechanisms I

Slower growth in population because of continuing decline in the desired completed family size, both in the rich and the poor world.

Slower growth in GDP because it is more difficult to increase labour productivity in the quaternary sector (non-robotizable culture and care), than in the primary (food), secondary (industry) and tertiary (services) sectors.

Slower growth in consumption, because of the need to use labour and capital for unavoidable expenditure:

For repair – to undo damage from pollution, extreme weather, and social unrest

For more R&D – to reduce resource intensity and pollution intensity per unit of GDP

For more investment (i.e. construction) – to improve global resource supply and pollution control

For more investment in adaptation – to protect against future climate damage

Basic mechanisms II

World4 will be formulated in conventional macroeconomic language to simplify comparison with data and other analyses

World4 will distinguish between rich and poor (owners and workers) and between rich and poor countries.

World4 will distinguish between the real economy and the financial economy.

> In the **real** economy one needs to use labour, capital, and energy in order to 1) produce goods and services, or to 2) increase the productive capacity of the economy, or to 3) produce more resources or to 4) reduce pollution levels
>
> In the **financial** economy money flows determine the distribution of purchasing power (“demand in monetary terms”) in the population, and the ability of owners to complete construction projects (“invest”) if this serves their interest

Questions to be answered I

1 What is the most likely global future towards the year 2100?

2 How fast must decoupling occur if the world is to avoid serious dislocation (drop in average well-being) because of “resource shortages” before 2100?
In other words: *How much must decoupling be accelerated above current rates?*

3 Same question for “high pollution levels”

4 Same question for “insufficient food”

5 What tax increase would be required to finance 2, 3, and 4?

6 How fast must wealth be transferred from rich to poor to solve the problems in 2, 3, and 4 without accelerated decoupling?

7 How fast must wealth be transferred from rich to poor countries if all countries are to have more than 10 $ per person-day in 2050? This is equivalent to a GDP of 3.500 $ per person-year

Questions to be answered II

8 Same question for 20$ per person-day by 2100? This is equivalent to a GDP of 7.000 $ per person-year

9 How much wealth must be transferred from rich to poor in the rich world in order to maintain full employment? And what if the goal is to ensure a decent minimum annual income, of say 20.000 $/person-year, either in the form of a wage in return for work or as payment from the government to all citizens.

10 Is it possible to find other (simpler) ways to ensure that average wellbeing will increase monotonically over the decades ahead?
In the rich world? In the whole world?

World4 -> PEEC population, economy, energy climate

Output from three input factors
Output Q = ∫ Real capital K, Physical resources R, work (Labour) L
in a **Cobb-Douglas** type production function

$$Q = qk * K^{alpha} * qr * R^{beta} * ql * L^{(1- alpha- beta)}$$

where qk, qr, and ql are factors that may vary over time,
while the exponents alpha and beta are constants between 0 and 1.

Output *Q* is measured in "output units per year", where "output unit" is a physical unit, like for example "ton", "product", "person-hour of service", or something else, depending on the type of output.

The input factors *K*, *R*, and *L* are measured in "machine hours used per year", "tons of resources used per year", and "person-hours of work performed per year" respectively.

We scale everything to 1970

PEEC Technological development

Technology

In PEEC there is technological advance in the sense that one physical unit of the input factors *K, R, and L*, over time becomes capable of producing more output Q.

"The factor productivity grows exogenously" with growth rates k, r and l respectively, all measured in "percent per year").
The growth rates can be increased through higher investment in R&D.

We get the following production function where time t is measured in years from 1970.

$$Q = (qk * K*exp(k*\mathbf{t}))^{alpha}) * (qr * R*exp(r*\mathbf{t}))^{beta}) * (ql * L*exp(l*\mathbf{t}))^{(1-alpha-beta)})$$

PEEC Productivity growth

Productivity growth

We assume that productivity growth is lower in the services and care sectors than in the agriculture and industry sectors.

As a consequence, the growth rate in GDP per person is lower in a mature economy, where most of the work force works in services and (especially) care.

History shows that it is simple to automatise the production of food and industrial output, harder to computerise services, and difficult to robotise care.

In PEEK the total productivity in the economy is defined as GDP/population (measured in “dollars per person-year”).

It is neither labour productivity, defined as GDP/full time workers
(measured in “dollars per full time equivalent person-year”
or alternatively “dollars per person-hour”),

Nor the marginal labour factor productivity δGDP/δL (also measured in “dollars per person-hour”)

PEEC Four types of output

Four types of output

The total output (= annual production in physical terms) arises in four different sectors:

"**food**" – the primary sector (agriculture, fisheries and forestry),
"**industry**" – the secondary sector (manufacturing and construction)
"**services**" – the tertiary sector (ordinary personal and office services)
"**care**" – the quaternary sector (culture and care)

Two sub-activities within the four production sectors

"***Resource supply***" – the effort to maintain an adequate flow of resources, by development of new resource supplies, and technological development to reduce the need for resources per unit of output (lower resource intensity)

"***Pollution control***" – the effort to avoid environmental damage through investment in pollution control equipment and ecosystem repair, and in technological development to reduce the ecological damage per unit of output (lower pollution intensity)

PEEC Division of total income

Division of total income
Total income TI equals total GDP (until trade is introduced in PEEC at a later time)

Total income TI is split in three components, all measured in “dollars per year”. These are 1) savings, 2) consumption, and 3) non-discretionary spending - TNDS

Total non-discretionary spending TNDS
is the (small, but increasing) part of income which has to be spent to maintain an acceptable level of well-being on an increasingly crowded planet – for example on maintaining a sufficient flow of resources in spite of depletion, on maintaining acceptable environmental quality in spite of increasing pollution.

Some of this will be increased spending on infrastructure and equipment, some of it will be increased spending on R&D.

PEEC Division of total income

Total savings TS
is that part of income which is not used on consumption or non-discretionary (unavoidable) spending.

The population is divided in two groups: workers (who spend all their income) and owners (who spend only part of their income, and save the rest).

Consumption is done individually (based on after tax-income) or collectively (through tax-financed public consumption). Thus all savings are owned by "owners", and accumulate into total wealth W (measured in "dollars"). Owners can include the state.

Total consumption TC
is the rest of total income, after savings and unavoidable spending on non-discretionary output

Once we introduce trade in PEEC, we will distinguish between income and GDP

PEEC TID - Six investment flows

Total investment TID
money that is available for the construction of new plant and equipment. TID (measured in “dollars per year”) is a small fraction of the accumulated wealth W (= sum of the value of all assets held = potential credit, and measured in “dollars”). The two are related through the concept of “speed of money” in the classical macroeconomics literature. Our “speed of wealth” is TID divided by W and measured in “per year”.

The total flow of investment goods and services (measured in “machines (or capacity units) per year”) is calculated as the investment demand (in $/y) divided by the cost of new capacity (in $/cu). The total flow arises from within the four production sectors, in sufficient volume to match the total investment demand (measured in “dollars per year”).

TID is split into six investment flows (all measured in “dollars per year”) going into:
1) Food, 2) Industry, 3) Services, 4) Care, 5) Resources, 6) Pollution control
In each case the addition of new real capital (=new capital equipment and plant = new capacity, and measured in “capacity units per year”) equals the investment flow (in $/y) divided by the cost of new capacity (in $/cu).

PEEC Cost of resources and labour relative to value of output

Cost of resources and labour relative to value of output

$GDP_{PEEC} = \Sigma Q_{sector} * P_{sector}$ summed over all four sectors.
Q = output
p = the price per unit of output (and measured as “dollars per unit of output”)

$TC = \mu * K + \sigma * R + \omega * L$
TC = total cost (dollars per year)
μ = cost of capital / capacity (dollars per machine (capacity unit))
σ = cost of resources (dollars per ton of resources)
ω = cost of labor (dollars per person-hour)

PEEC Optimal use of resources and labour I

Optimal use of resources and labour
Given K, and given prices for inputs and outputs, we find the amount of R and L which gives the highest output Q for a given total input cost.

These amounts of R are called "optimal resource use" OR
and of L are called "optimal labour use" OL

OR and OL must satisfy $T_{otal}V_{alue} = T_{otal}O_{utput}$ for the given value of K, in other words

$TV = Q_{sector} * p_{sector} \quad = \quad TC = \mu * K + \sigma * OR + \omega * OL$
TV = total values = TC = total cost
or
$Q = \mu/p * K + \sigma/p * OR + \omega/p * OL$

Which means
$OR = (Q – \mu/p * K – \omega/p * OL) / (\sigma/p)$
$OL = (Q – \mu/p * K – \sigma/p * OR) / (\omega/p)$

PEEC Optimal use of resources and labour II

the relative prices of inputs and outputs can be converted to
three “technical coefficients” – one set for each of the four production sectors j.

mju = μ/p (measured in “machines (capacity units) worn out per unit of output”)
sigma = σ/p (measured in “tons used per unit of output”)
omega = ω/p (measured in “man-hours used per unit of output”)

thus

OR = (Q – mju * K – omega * OL) / sigma
OL = (Q – mju * K – sigma * OR) / omega

Since they both are part of Q in a nonlinear form we solve the equations iteratively

We assume actual resource use R moves towards optimal resource use OR over time (with a time constant of 3 years).
OR = (Q_{t-3} – mju * K_{t-3} – omega * OL_{t-3} / sigma

We assume actual labour R moves towards optimal labor use OL over the same 3yr.
OL = (Q_{t-3} – mju * K_{t-3} – sigma * OL_{t-3}) / omega

Population (in “persons”) is calculated as accumulated births less deaths (both in “persons per year”. The population is divided in four age groups (0-20 years, 20-40 years, 40-60 years, and 60 + years), each with its age-specific mortality rate (measured in percent per year) influenced by GDP per person and service output per person.
The birth rate (measured in per cent per year) is influenced by GDP per person and urbanization rate (measured as fraction of population urban).

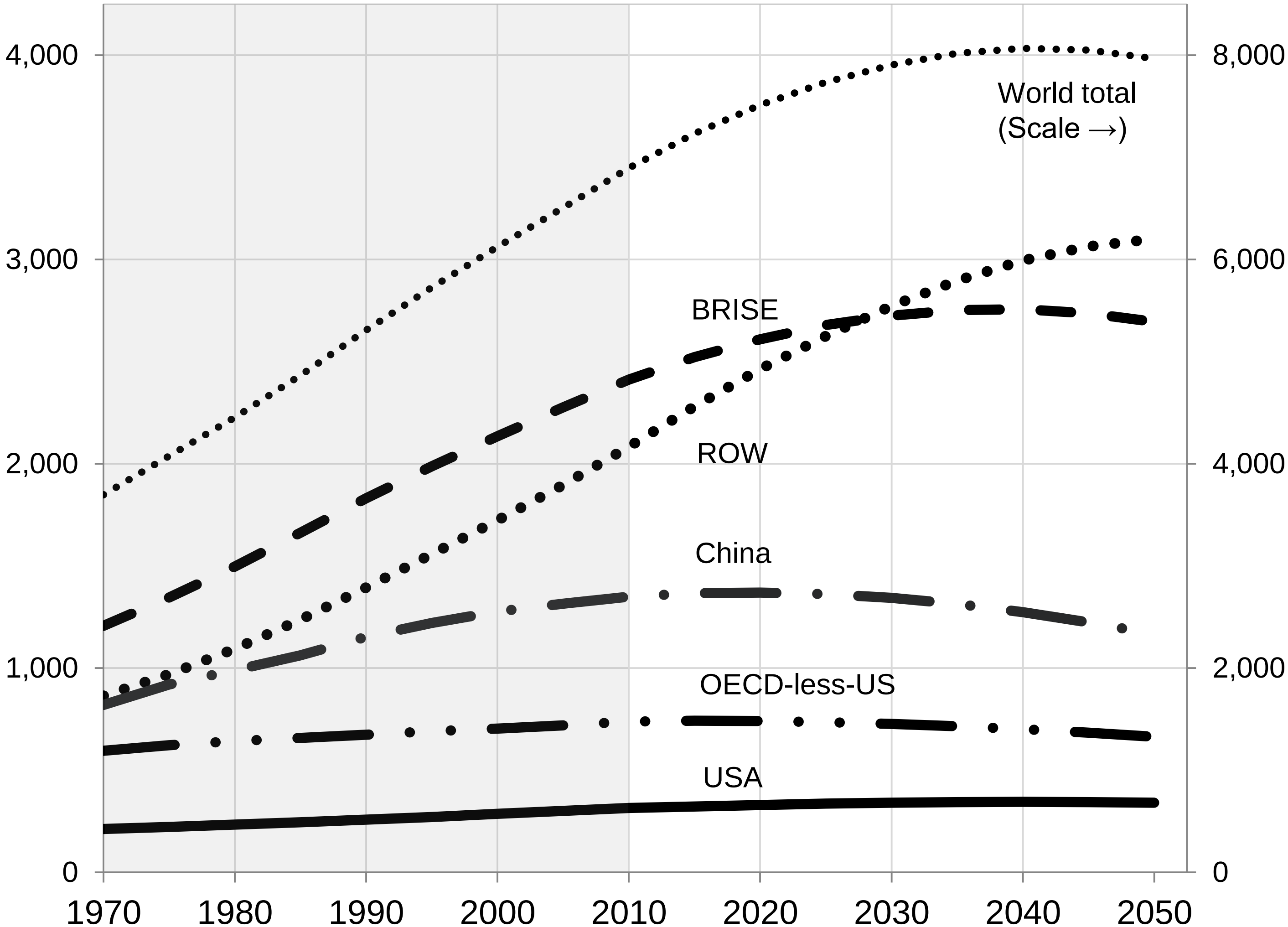
Labour force (measured in full time persons) is calculated as population aged 20-60 years (measured in persons) multiplied with average work done per person (in person-hours per person-year), which in turn equals workforce participation rate (measured in %) times average hours worked per employed person (in person hours per year)

PEEC Financial sector

Financial sector Is modeled as total wealth (measured in “dollars”), which is the accumulation of savings adjusted for price level and interest rates.

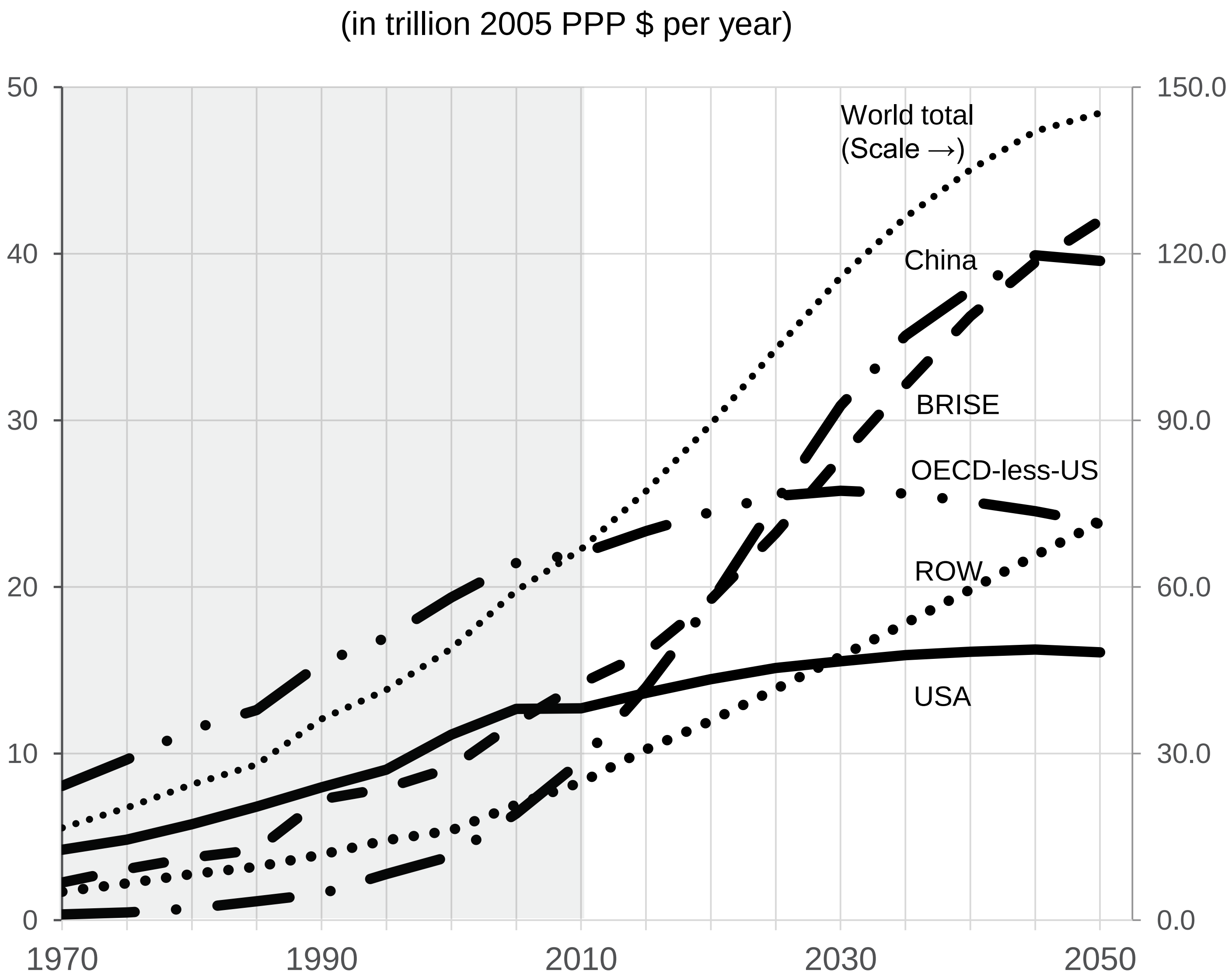
Every year a certain, small fraction of total wealth (measured in “dollars”)
is converted into investment demand (measured in “dollars per year”).
The fraction is determined by the real interest rate (is it worthwhile to invest?) and the amount of unsatisfied need in the four production sectors and the two sub-activities.

Population growth will slow



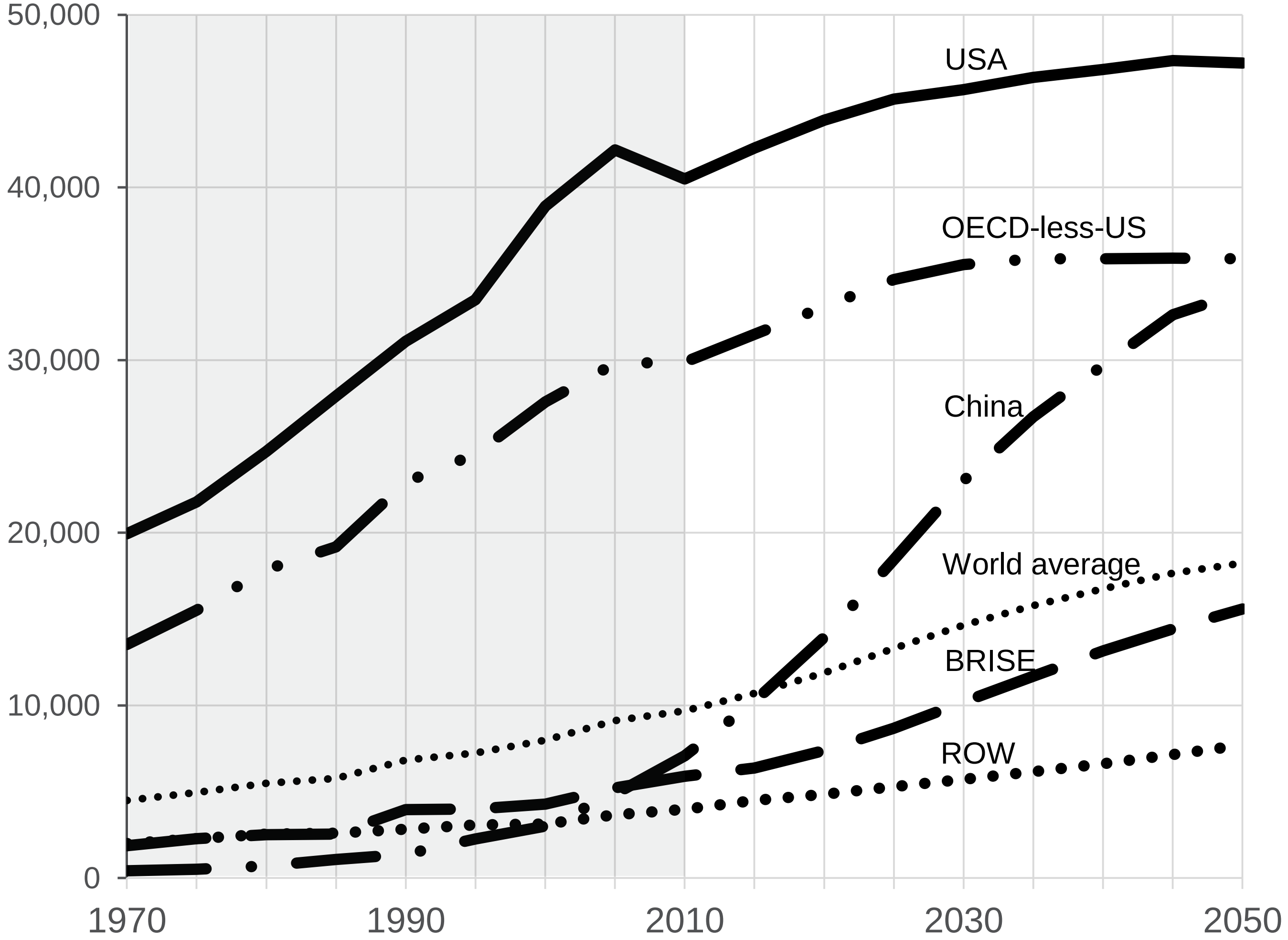
Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, 2012

Total output (GDP) will grow, but more slowly



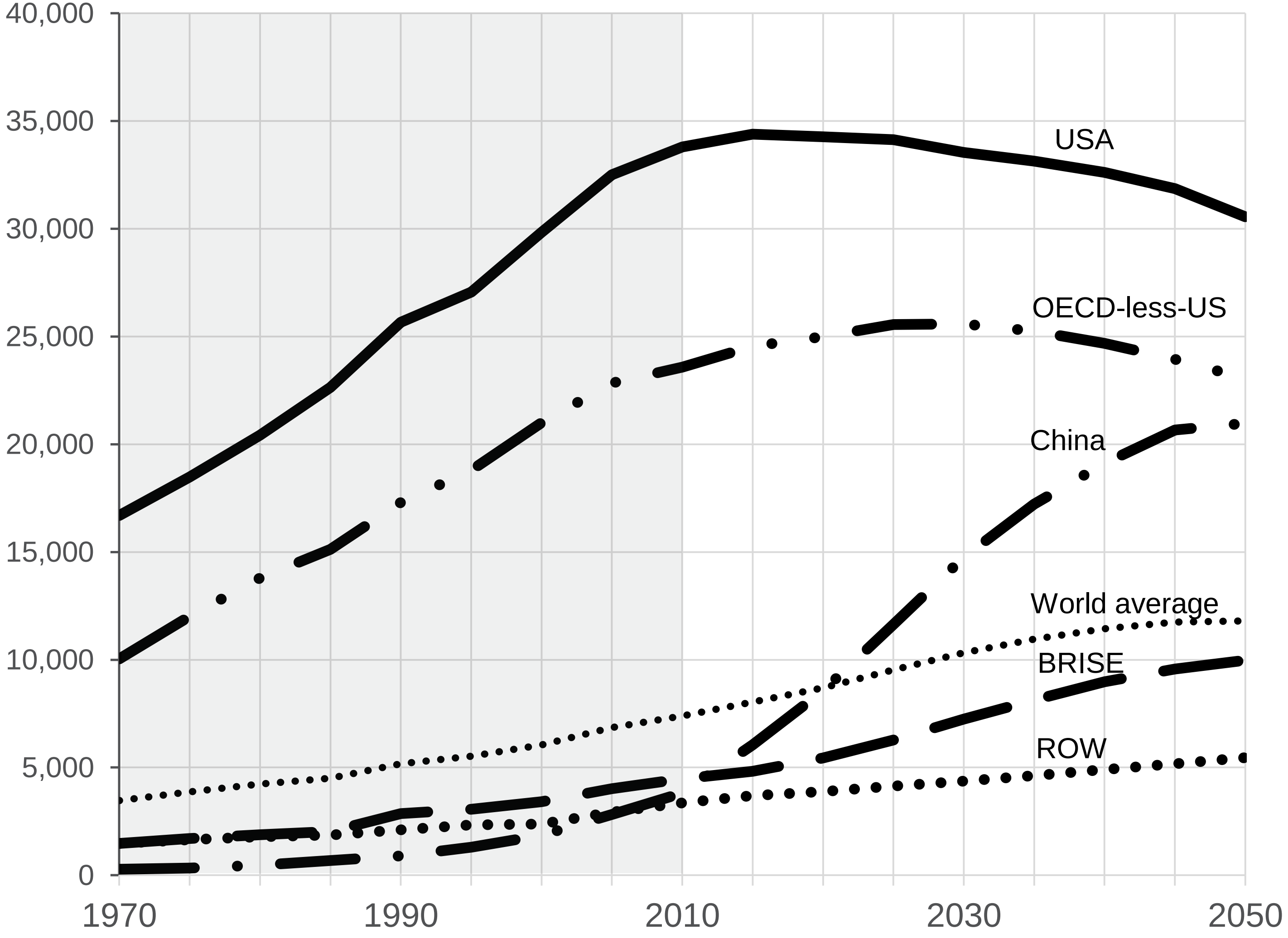
Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, 2012

GDP per person will evolve differently



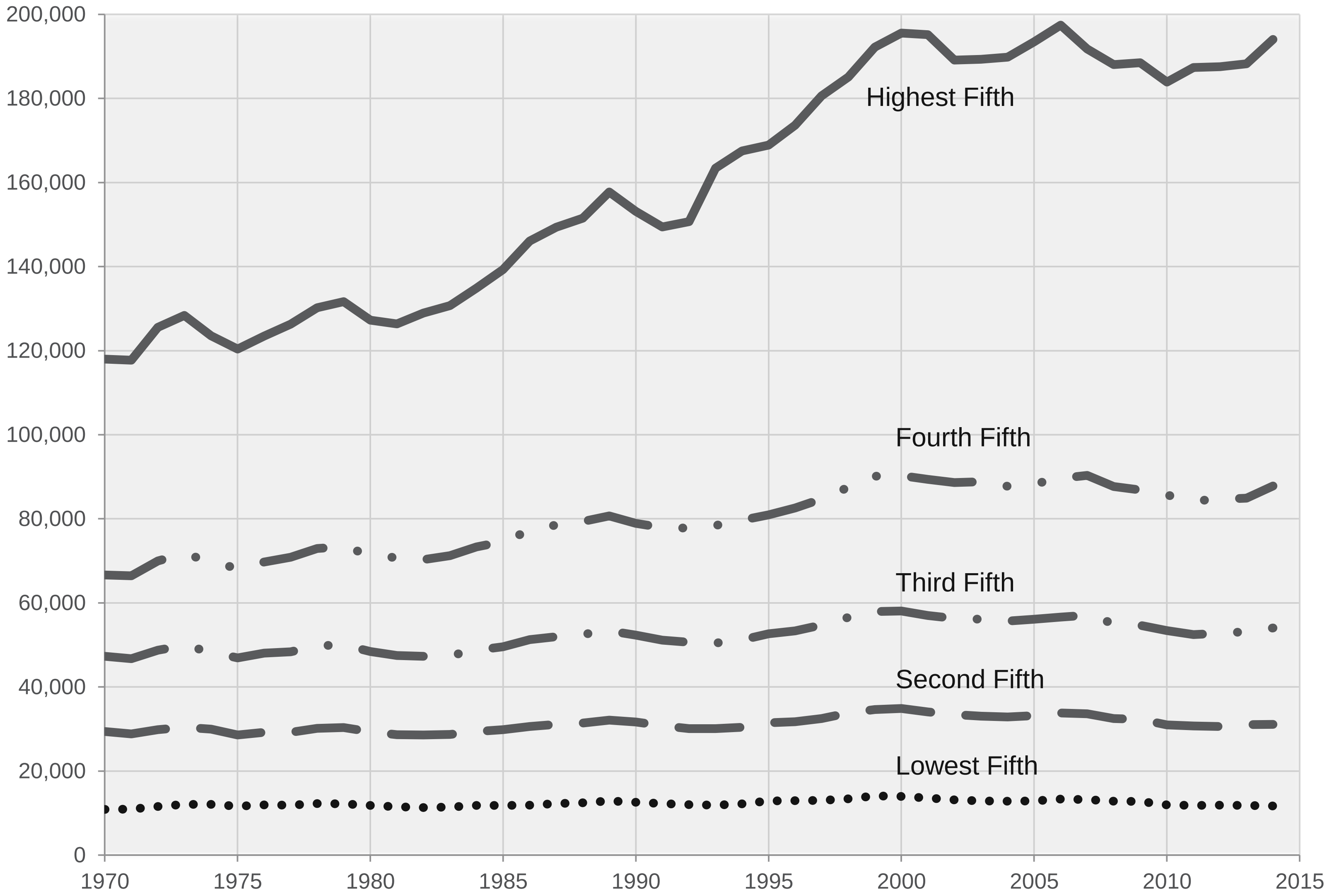
Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, 2012

Average disposable incomes will differ



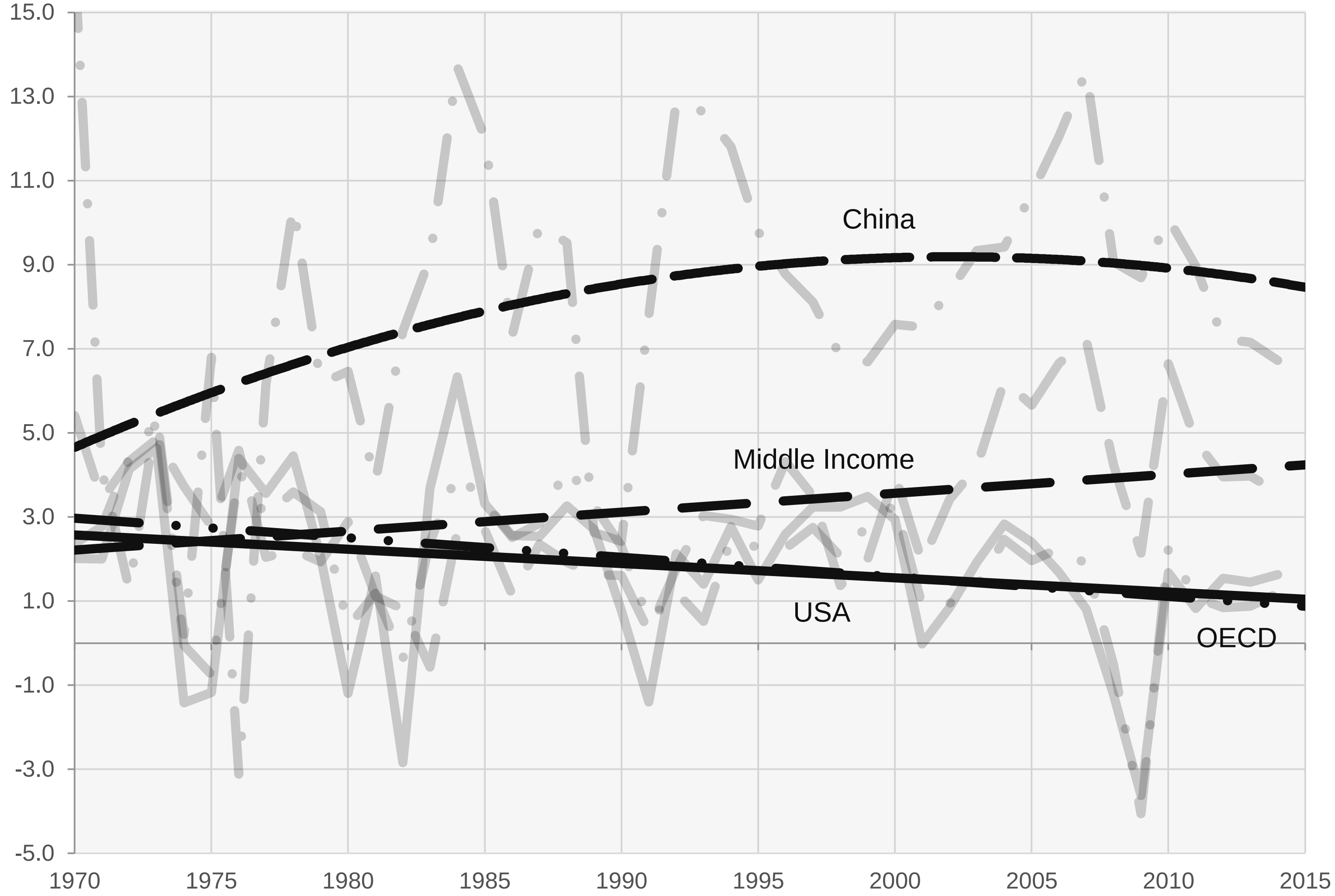
Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, 2012

Inequality is increasing, especially in the US

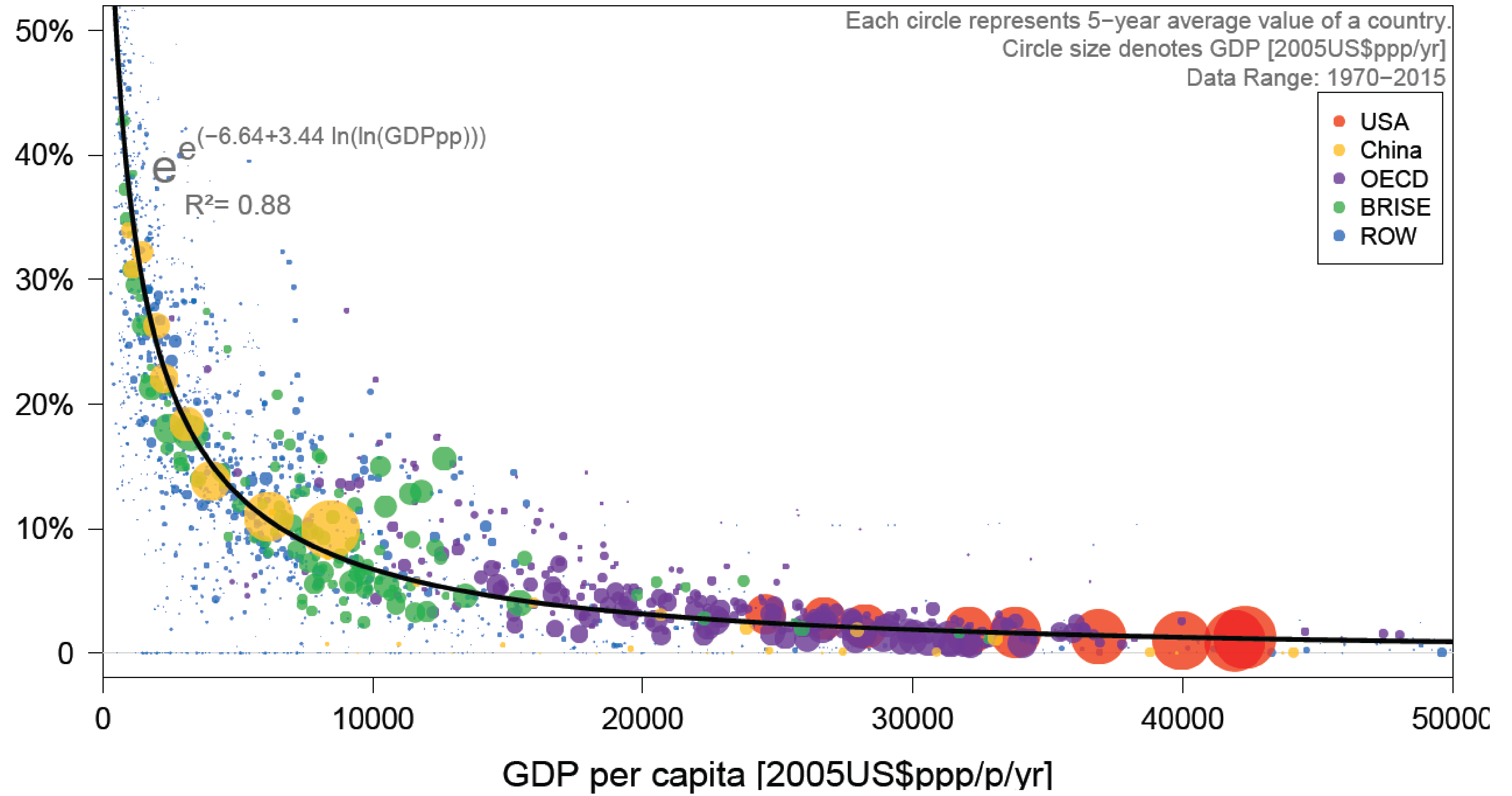


Source: U.S. Census Bureau, Current Population Survey, Annual Social and Economic Supplements.
https://www.census.gov/hhes/www/income/data/historical/inequality/

Growth rates will slow in the rich world, but not in the poor



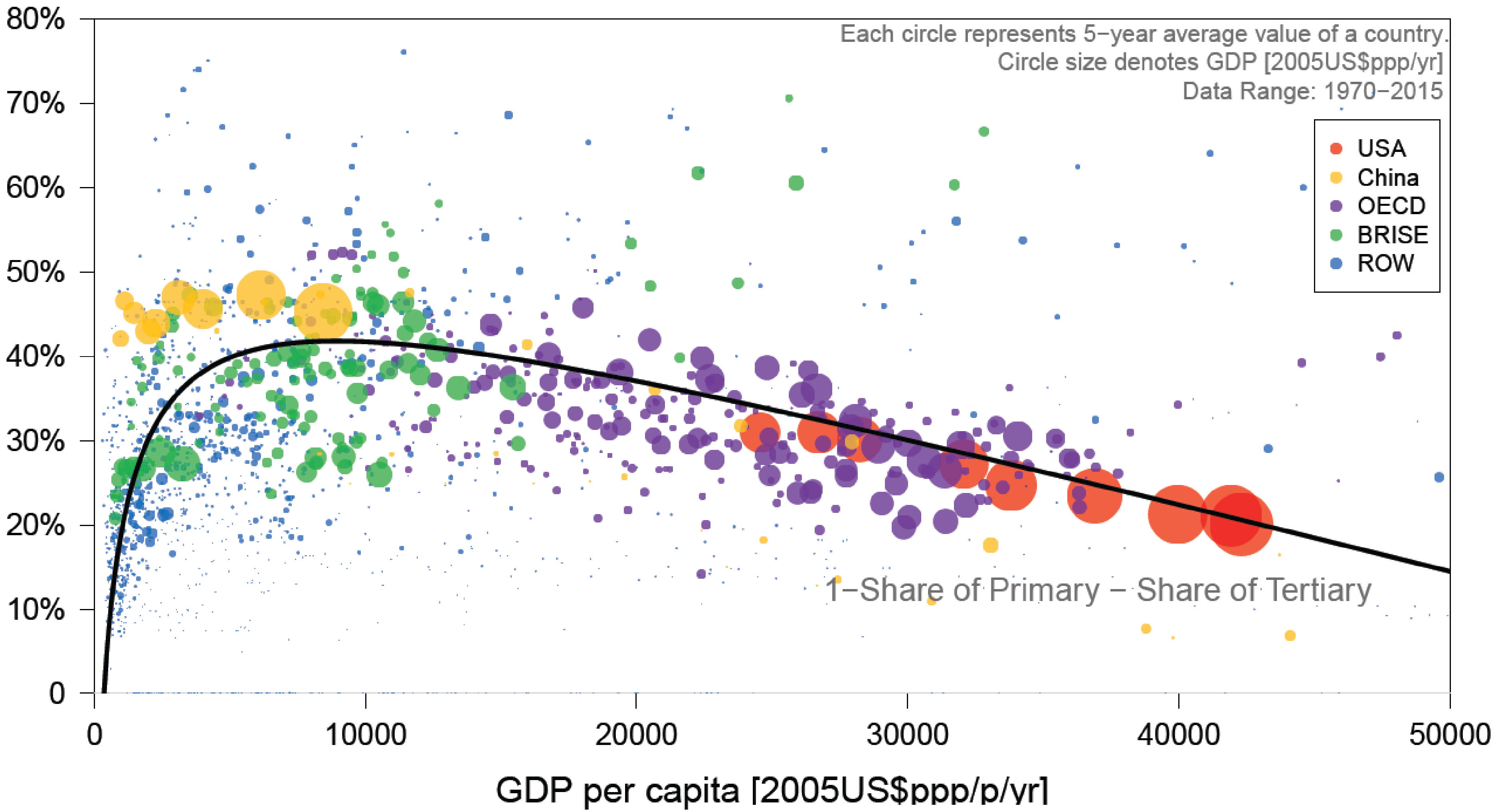
Percent of GDP in primary sector declines



ce: World Bank, Gapminder

Source: Future of Planet Earth project, DNV-GL, Høvik, Norway, 2016

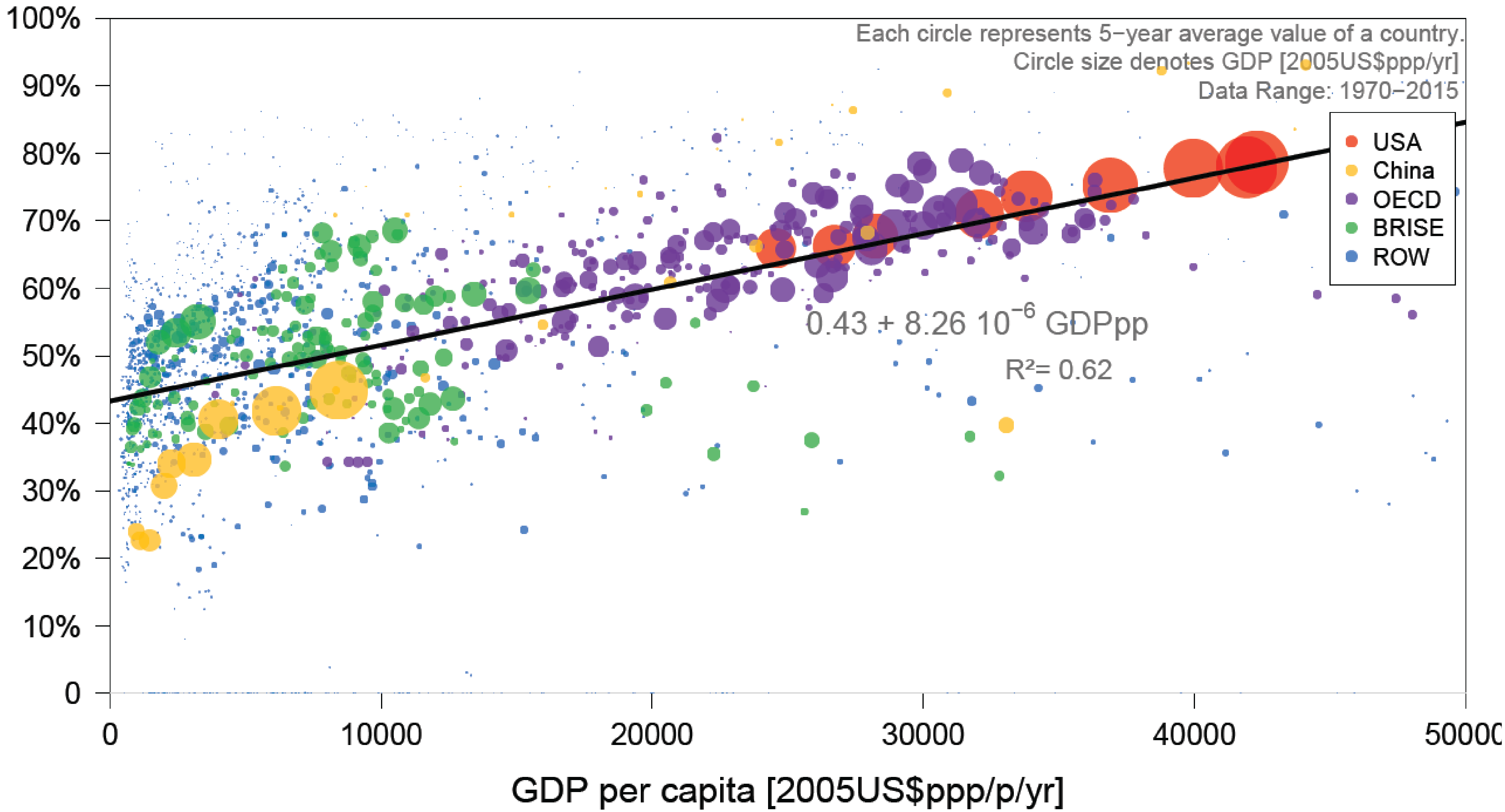
Percent of GDP in secondary sector declines



:e: World Bank, Gapminder

Source: Future of Planet Earth project, DNV-GL, Høvik, Norway, 2016

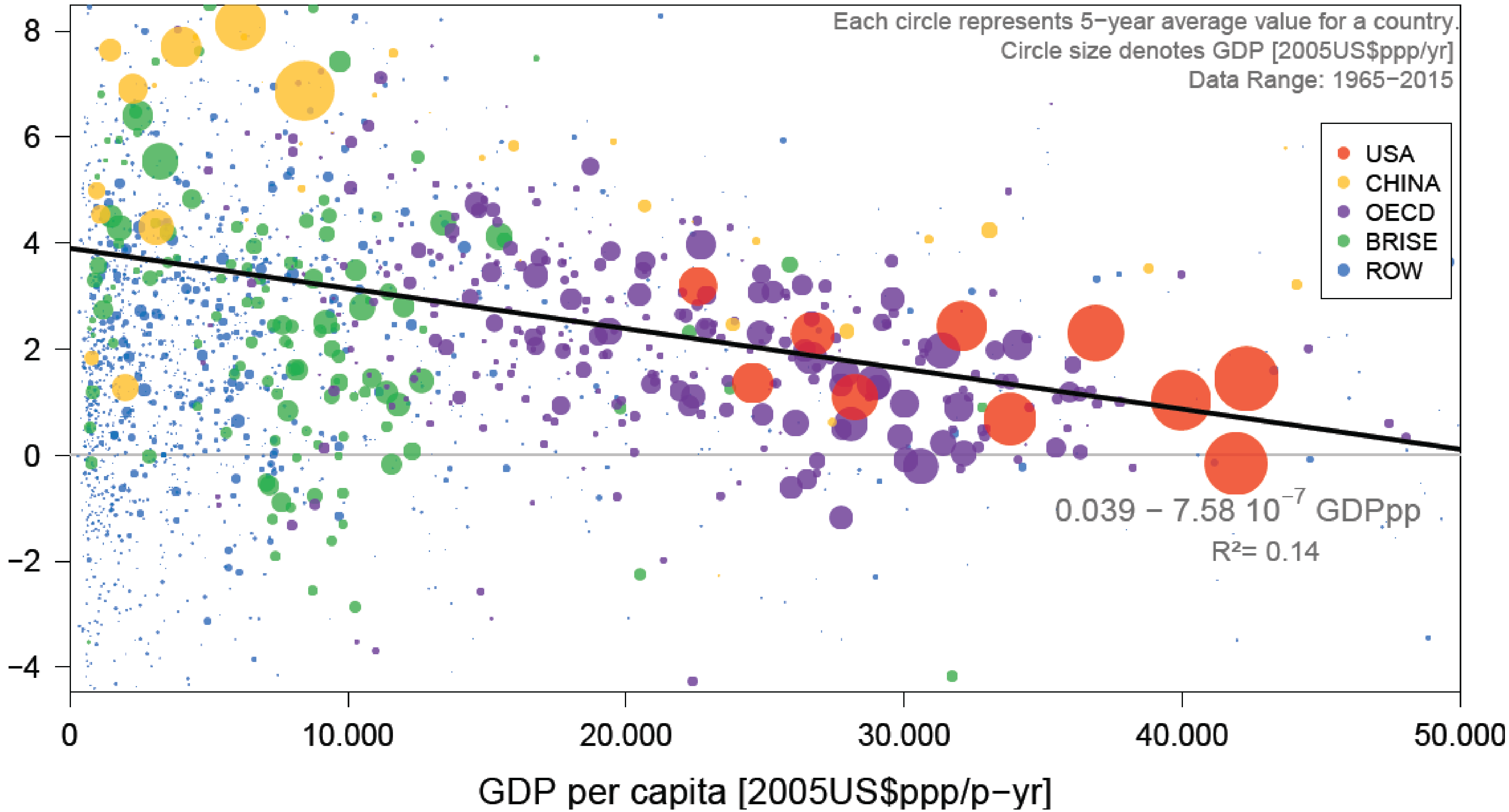
Percent of GDP in tertiary sector grows



urce: World Bank, Gapminder

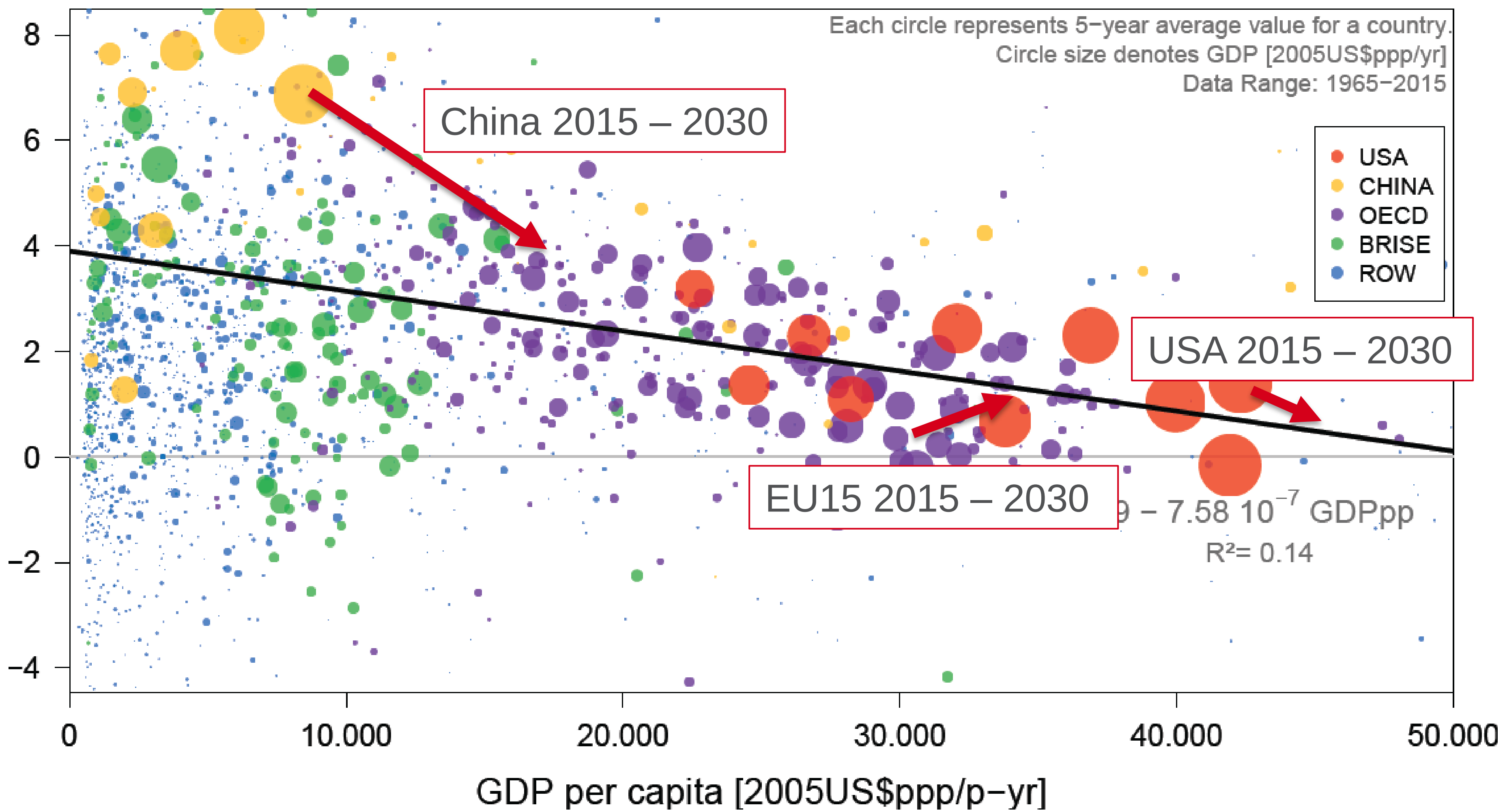
Source: Future of Planet Earth project, DNV-GL, Høvik, Norway, 2016

Growth (%/yr) in GDP per person slows



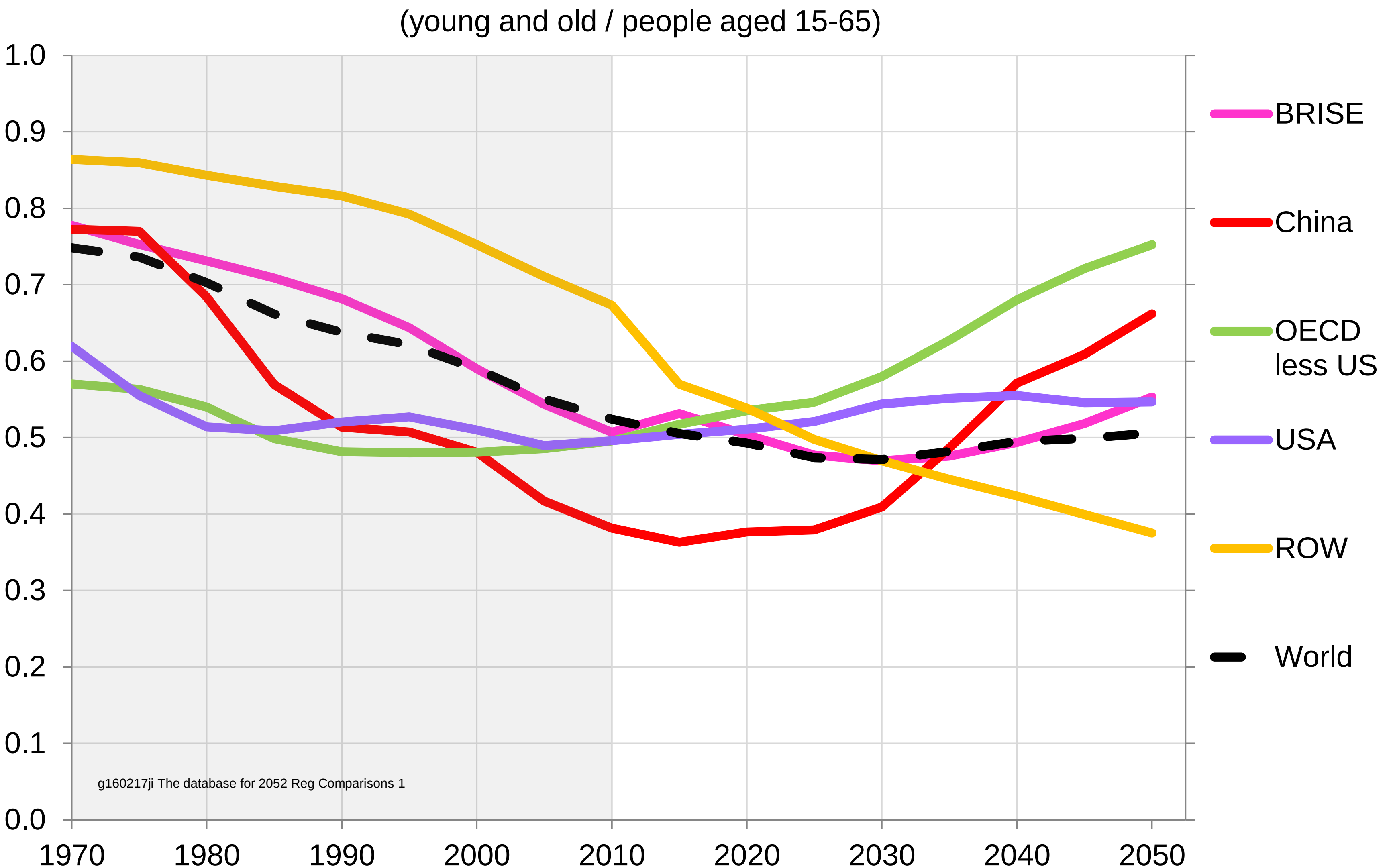
Source: Future of Planet Earth project, DNV-GL, Høvik, Norway, 2016

Likely growth rates (%/yr) in GDP per person



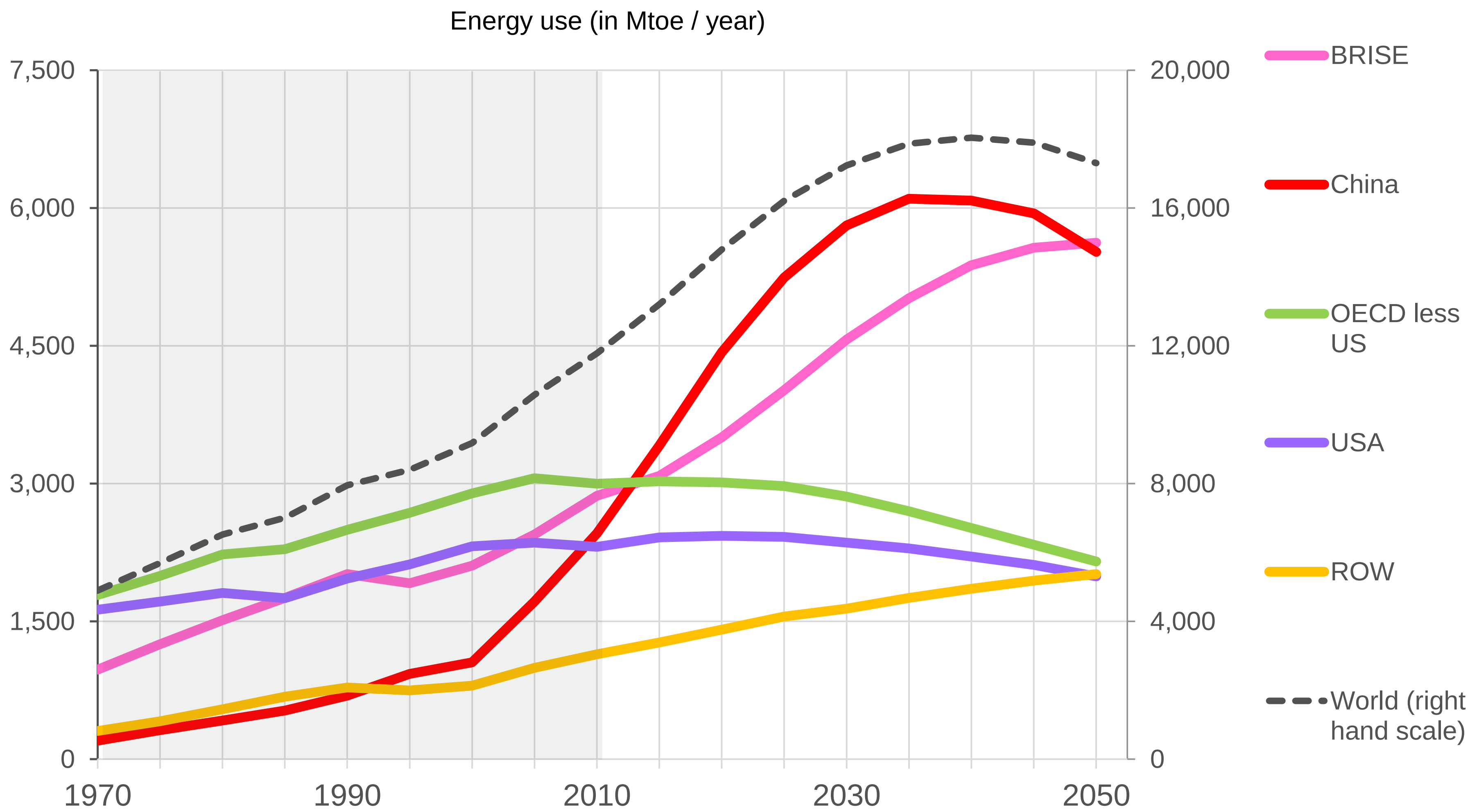
Source: Future of Planet Earth project, DNV-GL, Høvik, Norway, 2016

The dependency ratio will stay rather low



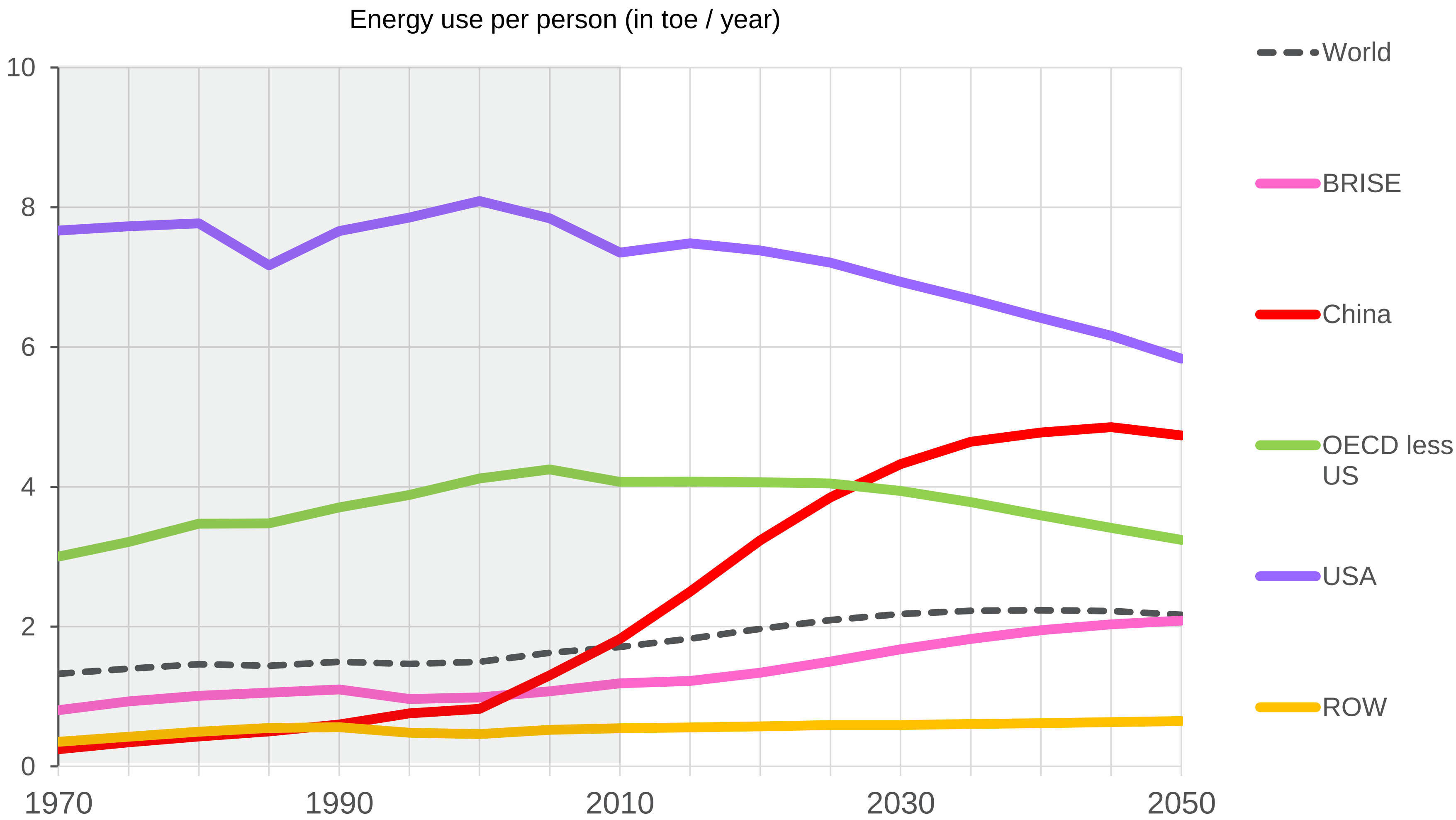
Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, May 2012

Global energy use will rise to a peak in 2040



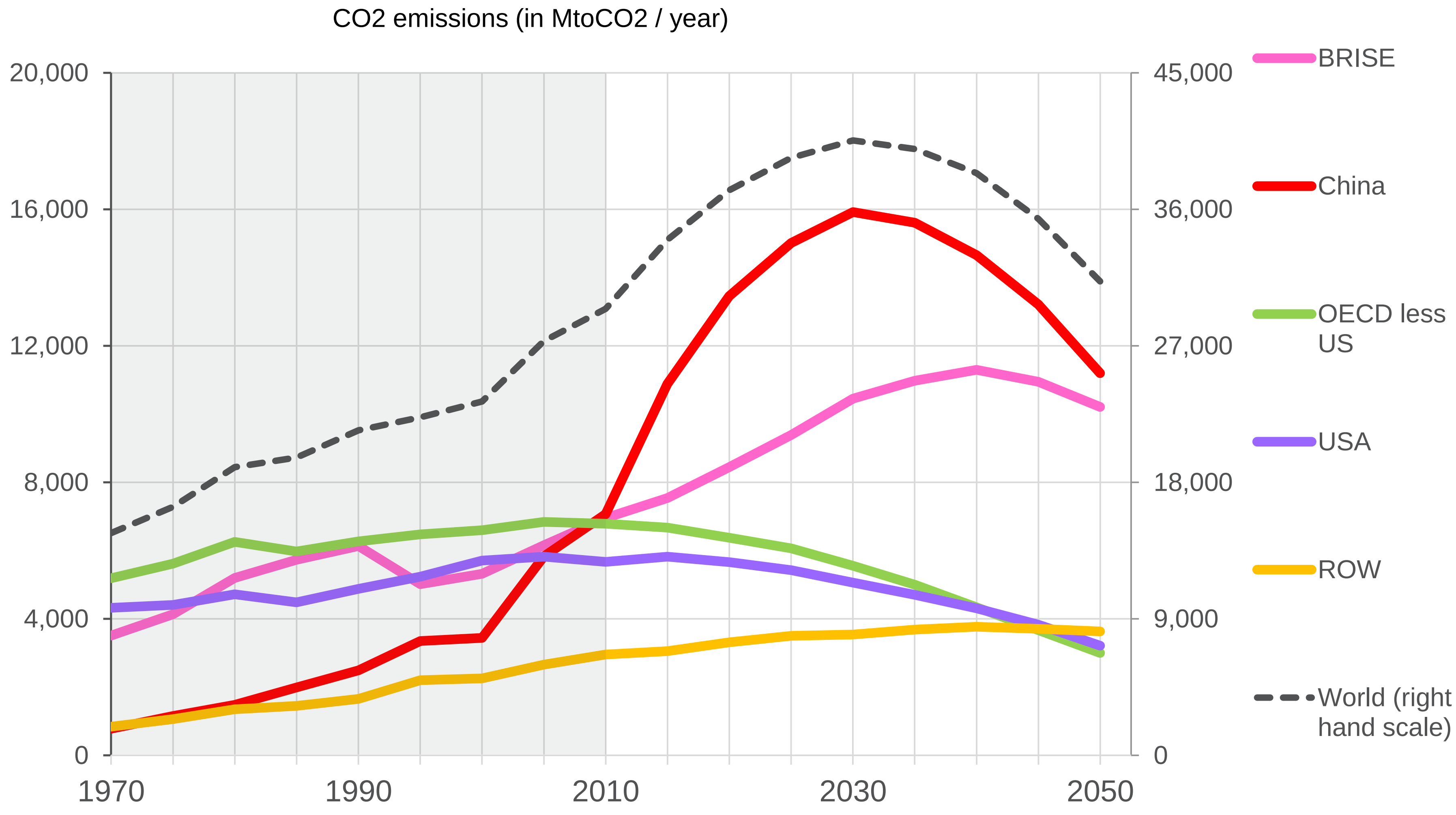
Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, May 2012

Energy use per person will slowly converge



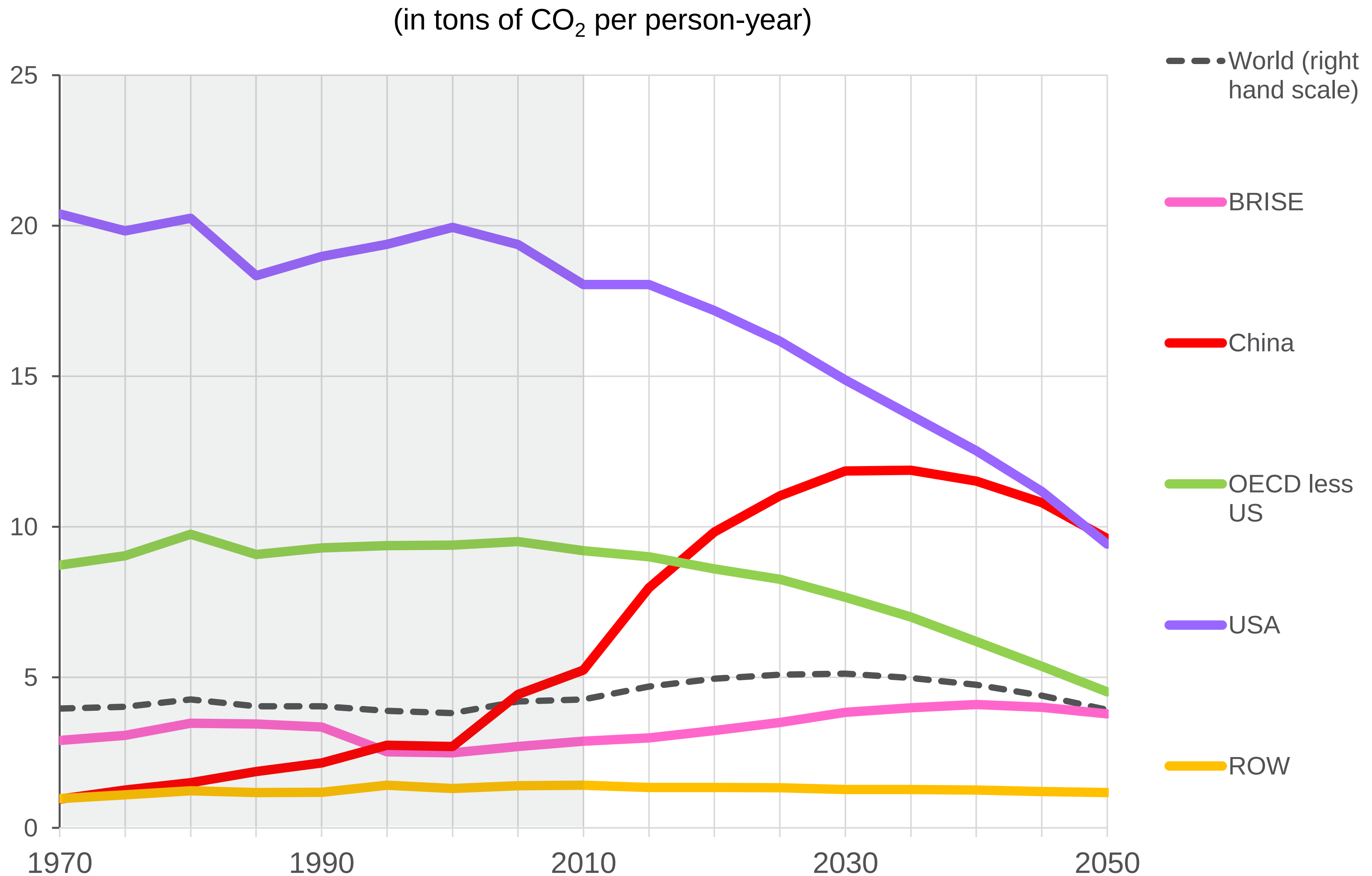
Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, May 2012

Global CO_2 emissions will peak in 2030



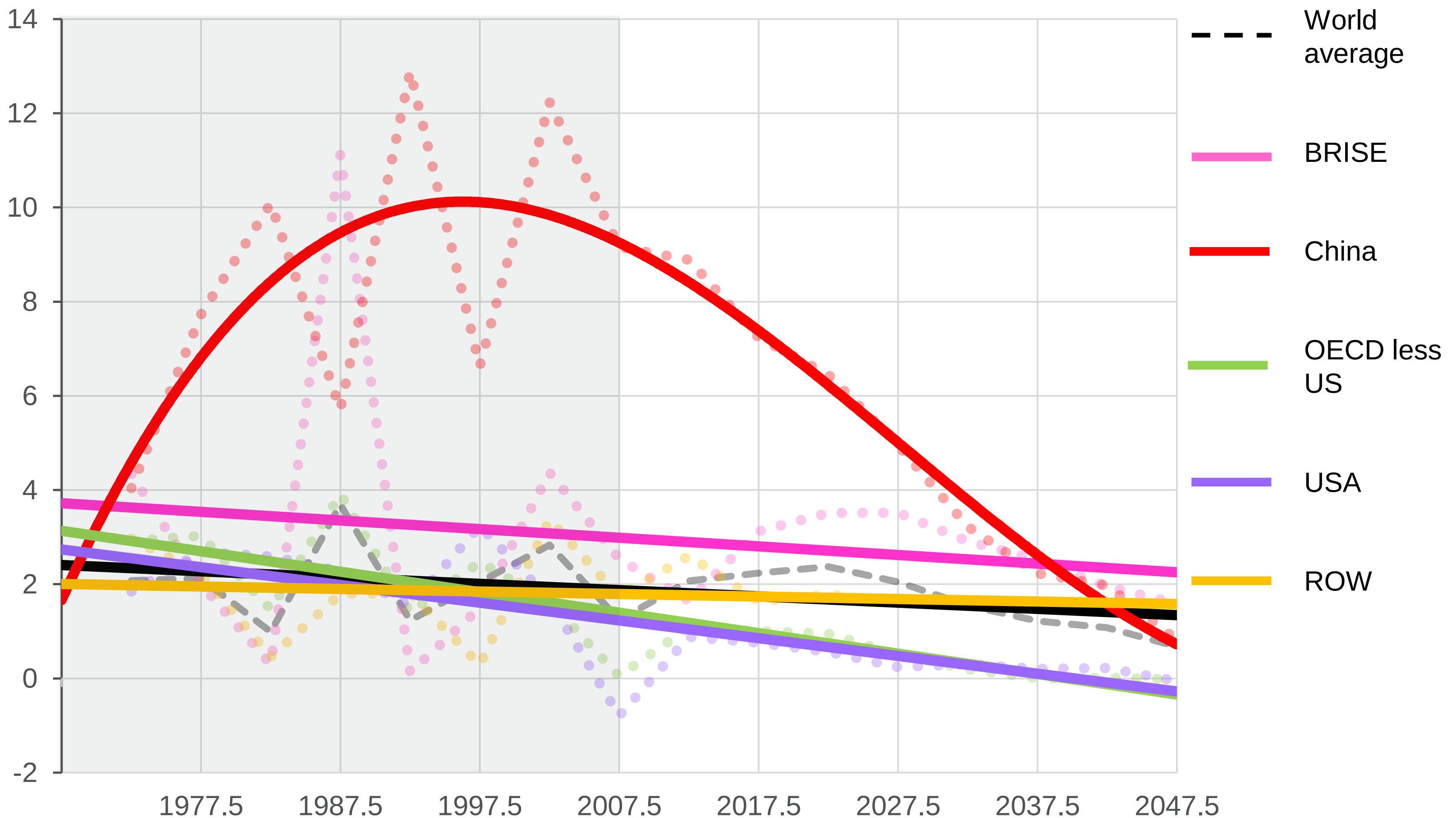
Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, May 2012c

CO_2 emissions per person will finally decline



Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, May 2012

Growth in GDP pp (% pa)



Source: Jorgen Randers, *2052*, Chelsea Green, Vermont, May 2012