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Abstract

The emission targets adopted in the Kyoto Protocol[1] far exceed the likely level of emissions from Russia and Ukraine.[2,3] These countries could sell their "bubbles" if the Protocol enters into force and industrialized countries establish an international emission trading system. Using the most recent, comprehensive scenarios[2] for emissions of carbon dioxide from the energy system we estimate that during the Protocol's 2008-2012 "budget period" the bubble will range from 9 MtC (million tons of carbon) to 900 MtC for Russia and 3 MtC to 200 MtC for Ukraine. Even scenarios with high economic growth and carbon-intensive technologies do not burst the bubble before the budget period. In the central ("middle course") scenario the total carbon bubble exceeds 1000 MtC, is worth 22 to 170 billion US Dollars (4 to 34 billion US Dollars per year), and does not burst until 2040. This flow of assets, which could exceed Russian earnings from natural gas exports ($10 billion in 1997[4]), is comparable with projected total investments in the Russian energy system for 2008-2012. If directed towards low-carbon infrastructure investments (e.g., gas pipelines, safe nuclear power), bubble transfers could reinforce and partially lock-in decarbonization of the world energy system.

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The Kyoto Protocol Carbon Bubble: Implications for Russia, Ukraine and Emission Trading

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The 1997 Kyoto Protocol to the Framework Convention on Climate Change (FCCC) requires that industrialized countries, listed in Annex I, cut their annual emissions of greenhouse gases an average of about 5% below 1990 levels during 2008-2012. Annex B of the Protocol allocates that collective target among 38 countries and the European Community. Those targets apply to sources and sinks of six greenhouse gases; for simplicity, in this analysis we consider only the most important human cause of global warming: CO_2 released during combustion of fossil fuels.

The Protocol allows creation of various systems for emissions trading system in which countries that exceed their Annex B target can remain in compliance by purchasing surplus permits from other Annex B countries (Articles 4, 6 & 17 of Ref. 1). As with any trading system, the flow and value of emission permits will depend upon their initial distribution, supply and demand. Here we focus on the aspect of that potential trading system that has been the most politically sensitive: the number and value of permits that were granted to Russia and Ukraine, which we term the "carbon bubble." (Observers politically hostile to this allocation of assets have dubbed it "hot air.")

The Kyoto commitments require that both Russia and Ukraine freeze emissions at 1990 levels. Because of economic disarray with the collapse of the Soviet empire and central planning, CO_2 emissions peaked in the late 1980s, declined sharply in the early 1990s, and are likely to remain below 1990 levels in the near future.

The size and value of the bubble will depend on the level and timing of recovery relative to the 2008-2012 "budget period" as well as technological choices. Because these factors are especially difficult to predict, we employ six scenarios developed at the

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International Institute for Applied Systems Analysis (IIASA) and World Energy Council (WEC) that are especially suited to long-term global-scale analysis of the energy system. They encompass three cases of future developments (A, B, and C) subdivided into six alternative scenarios (A1, A2, A3, B, C1 and C2). Case A envisions a future of impressive technological improvements and consequent high economic growth. It has three variants, which reflect alternative futures for fossil fuel resources that can be tapped and non-fossil technologies. In scenario A1, oil and gas are abundant and remain the dominant fuel sources. In scenario A2, oil and gas are scarce and thus coal becomes the dominant source. In scenario A3, improvements in non-fossil technologies (renewables and nuclear) lead to the long-term elimination of fossil fuels for reasons of economy rather than scarcity. Case B is a central "middle course" scenario. Case C envisions a "green" future with substantial technological progress, unprecedented international cooperation to protect the environment, and measures to attain international equity. In Scenario C1 nuclear power is a transient technology that is replaced by non-nuclear low-carbon technologies such as solar hydrogen, while in scenario C2 new reactor technologies lead to renewed growth in nuclear over the same period. For the near-term Kyoto period, the most important differences between the scenarios are the level of economic growth (high in A, moderate in B and C) and the technologies employed (high carbon in A2; medium carbon in A1 and B; low carbon in A3, C1 and C2).

The IIASA-WEC scenarios are especially useful for analyzing the demand for and supply of carbon bubble permits because they provide both global coverage and harmonized regional detail. For each scenario the Study Team quantified basic assumptions (e.g., population and GDP) and calculated outputs (e.g., CO_2 emissions) through iterative use[2,5,6] of two models: (a) an 11 region version of the macroeconomic model "Global 2100,"[7] and (b) IIASA's linear programming energy system model "MESSAGE III."[8] The scenarios were reviewed extensively by over 100 regional experts through two rounds of publications in 1995[9] and 1998.[2]

Figure 1 shows estimated carbon emissions for Annex I countries for these six scenarios and, for comparison, all other published scenarios. Table 2 reports the difference between those estimated emissions levels and the targets adopted in the Kyoto Protocol. In all scenarios the "reforming" industrial economies of Eastern Europe and the former Soviet Union are in surplus. In nearly every scenario, the largest surplus is from the former Soviet Union.

In principle, carbon bubbles could exist in many of the 8 East European and 5 former Soviet countries listed in Annex B of the Kyoto Protocol. However, in practice, only Russia and Ukraine are likely to sell substantial quantities of bubble permits. The surplus in the East European region (table 2) is largely the consequence of four nations (Bulgaria, Hungary, Poland, and Romania) adjusting their base years to dates prior to 1990 when emissions were higher, which has given these countries targets that are less stringent than suggested by Annex B (see caption to table 2). Those base year adjustments also account for why the collective CO_2 cut for all Annex I nations is only 4.7%, rather than the 5% goal set for all greenhouse gases in the Kyoto Protocol. However, the two largest of these countries (Hungary and Poland) are developing close economic ties with the European Union; it may be politically difficult for these countries to sell their bubbles since the EU has steadfastly opposed emission trading. Three of the former Soviet republics—the Baltic states of Estonia, Latvia, and Lithuania—listed on Annex B have stringent (-8%) targets and are unlikely to have much surplus available for sale.

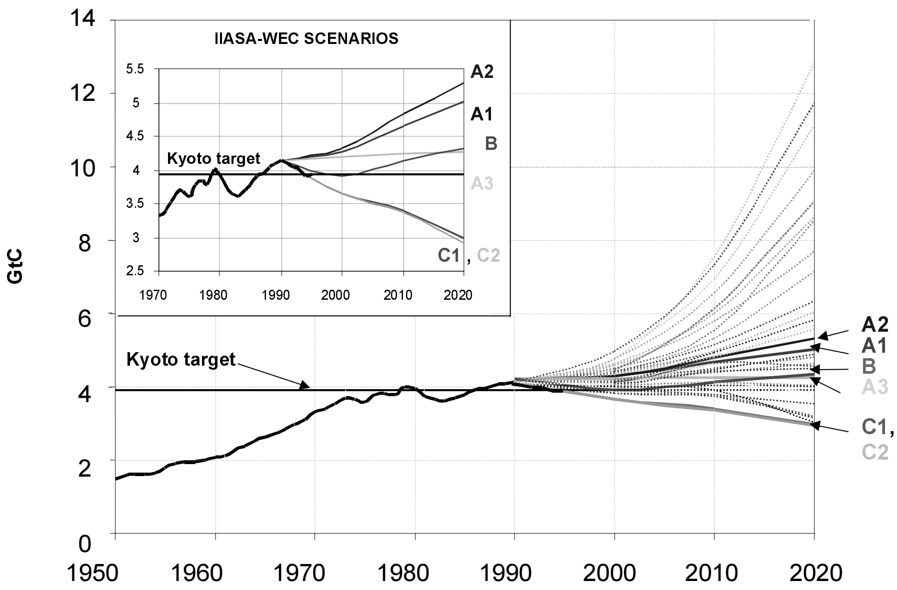

Figure 1: Annex I emissions of CO_2 due to combustion of fossil fuels for the six IIASA/WEC scenarios[2] (heavy colored lines and inset), all other published scenarios for Annex I (light lines), and actual emissions (black line). In the early 1990s, Annex I as a whole tracks the case C scenarios most closely because of deep reductions in CO_2 from the reforming countries. Other scenarios are drawn from the Morita and Lee[3] comprehensive database of 416 scenarios from 171 literature sources (including scenario evaluation activities such as the Energy Modeling Forum and the International Energy Workshop) compiled by for the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES). Historical data are from Oak Ridge National Laboratory (through 1990, excluding cement manufacture)[10] and updated with adjusted data from the International Energy Agency.[11] 1991 data are interpolated because adequate data for the former Soviet region are unavailable.

In 1990 Russia and Ukraine accounted for 650 MtC (63%) and 180 MtC (17%) of emissions from the former Soviet Union, respectively. For comparison, official data reported by Russia to the FCCC indicates 1990 emission levels of 648 MtC.[20] Ukraine has not reported official emission estimates. Table 3 compares projected emissions under the six scenarios for these two countries with the Kyoto targets for 2008-2012. The range of numbers is indicative of a plausible range in the possible magnitude of the bubble.

Figure 2 shows the scenarios for the former Soviet Union. The IIASA-WEC scenarios (especially B) track historical emissions closely. They are also systematically lower than most other scenarios, which reflects that other studies probably over-estimate emissions from this region for at least one of three reasons. (1) Some scenarios employ base years prior to 1990 when emissions were higher. (2) Most scenarios are long-term with the first reporting year of 2010 and thus do not provide the resolution needed to determine compliance with short-term targets such as in the Kyoto Protocol. (3) Even the few available shorter-term scenarios have systematically underestimated the depth of economic recession (e.g., refs [12] and [13]) or have not employed transparent data and methods to allow reproduction of the numbers (ref. [14]).

Table 1: IIASA/WEC Scenarios, summary of main indicators for 2020 and 2050. The A and B series are “non-intervention” (i.e. they do not include policies to limit carbon dioxide beyond what nations have already implemented today). Series C include a tax that rises steadily, beginning after 2000, to $200 per ton of carbon by 2100. Some proceeds from the tax are distributed to developing countries to compensate them for the costs of slowing global warming.

	Case					
	A		B		C	
	High growth		Middle course		Ecologically driven	
Population, billion	Global	FSU	Global	FSU	Global	FSU
1990	5.3	0.29	5.3	0.29	5.3	0.29
2020	7.9	0.35	7.9	0.35	7.9	0.35
2050	10.1	0.39	10.1	0.39	10.1	0.39
GDP, trillion US(1990)$						
1990	20.9	0.79	20.9	0.79	20.9	0.79
2020	46.9	1.13	40.2	0.97	40.5	1.08
2050	101.5	5.6	72.8	3.0	75	2.8
Primary energy intensity, annual improvement						
1990-2020	-0.9%	-0.3%	-0.8%	-0.9%	-1.4%	-1.1%
1990-2050	-1%	-1.9%	-0.8%	-1.7%	-1.4%	-2.2%
Primary energy demand, Gtoe						
1990	9	1.4	9	1.4	9	1.4
2020	15.4	1.9	13.5	1.3	11.4	1.4
2050	24.8	3.1	19.8	1.9	14.2	1.3
Technology costs						
Fossil	Low		Medium		Medium	
non-fossil	Low		Medium		High	
Environmental taxes	No		No		Yes	
Net carbon emissions, GtC						
1990	5.9	1.0	5.9	1.0	5.9	1.0
2020	8.2-9.9	1.0-1.2	8.3	0.8	6.3	0.8
2050	9.3-14.7	1.5-2.0	9.6	1.1	5.1-5.3	0.7
Number of scenarios	3		1		2	

Table 2: Emissions of carbon dioxide due to combustion of fossil fuels in the five regions that constitute Annex I ("Industrialized") countries. The table shows emissions in 1990, the target adopted in Kyoto, and the level of emissions that are in excess (or below) the five-year Kyoto target. Targets are expressed as the percentage change from 1990 levels and are weighted to account for two factors. (1) Within each region, national targets vary; in the absence of robust predictions for future emissions of every country, we weighted the national targets according to 1990 emissions. (For illustrative purposes, when weighting targets we ignore the small fraction of emissions from the East European and former Soviet nations that are not subjected to Annex B targets.) (2) As permitted by Decision of the Conference of the Parties to the FCCC,[15] four countries in Eastern Europe (Bulgaria, Hungary, Poland, Romania) have selected non-standard base years. Emissions in those base years are higher (15% to 17%) than in 1990, which makes the Kyoto target for those countries, in effect, less stringent. If base year adjustment were not allowed and all other factors had remained constant, the weighted Kyoto target for Eastern Europe would have been –7%. CO_2 emissions are net values, which exclude feedstocks, gas used for enhanced oil recovery, and non-energy emissions.

	1990 level	Kyoto target	Deficit (surplus) emissions					
	(MtC)	(weighted)	A1	A2	A3	B	C1	C2
Western Europe	956	-7.8%	1093	1351	687	731	-378	-368
North America	1491	-7.2%	2388	2741	1402	1838	-940	-1135
Pacific OECD	372	-3.1%	295	329	221	128	-217	-207
Eastern Europe	284	3.3%	-60	-47	-258	-345	-374	-368
Former Soviet Union	1026	-0.2%	-154	-7	-572	-1377	-832	-864
ANNEX I, TOTAL	4130	-4.7%	3605	4411	1523	1019	-2697	-2898

For Annex I as a whole only the "green" scenarios (C1 and C2) lead to emissions below the Kyoto targets, which suggests that in the absence of emission trading compliance with the Kyoto Protocol can be attained only with radical shifts in technology. In other scenarios, some advanced industrialized nations (Australia, Japan, New Zealand, North America, and Western Europe) can attain compliance by purchasing permits from regions in surplus. However, in none of those scenarios are the Russian and Ukrainian bubbles sufficiently large that all of the advanced industrialized nations can comply with the Protocol merely through acquisition of bubble permits.

To estimate the resources that might flow as the carbon bubbles are traded, we consider several prices for permits. For a low price we use $20 per ton, which is within the range ($14 to $23) quoted in the much-cited study by the US Council of Economic Advisers on the cost of implementing the Kyoto Protocol.[16] Many other analysts (e.g., ref. [17]) have criticized that study's assumptions, such as the widespread availability of low-cost carbon abatement options and extensive markets in emissions permits. Thus we consider two other permit prices that are characteristic of results using macroeconomic models for Kyoto-like runs with realistic assumptions: $50 per ton (optimistic assumptions) and $150 (pessimistic assumptions, such as inefficient markets). Other studies of Annex I trading cite similar prices,[17,18] but the range of plausible permit prices remains wide because there is no agreement among experts on the cost of carbon abatement nor the near-term feasibility of establishing various forms of emission trading, including trading with developing countries. It is possible that during transient periods (including the 5-year Kyoto "budget period") that permit prices could be much higher, especially if intertemporal permit borrowing is restricted. Table 4 shows the estimated values of the carbon bubbles with these assumptions.

Table 3: Russia and Ukraine emissions of carbon dioxide from combustion of fossil fuels. Values (MtC) are the surplus relative to the Kyoto target for the six IIASA/WEC scenarios. National figures are weighted from the total for the FSU region (63% and 17% for Russia and Ukraine, respectively). The Kyoto target (0%) is slightly different from the value in table 1 because the latter includes the –8% targets for Estonia, Latvia and Lithuania. We assume that Russia and Ukraine account for 63% and 17% of the Former Soviet Union on the basis of adjusted 1990 data from the International Energy Agency (ref. [19], p.31). These data are probably uncertain by as much as 10% but are consistent with other sources. Using these fractions, we calculate that 1990 fossil fuel CO_2 emission levels were 650 MtC (Russia) and 178 MtC (Ukraine). These fractions and numbers are also consistent with historical data for the former Soviet Union compiled by Oak Ridge National Laboratory (see figure 2 and ref. 10). The IIASA/WEC emissions are reported only on a decadal basis, which we have interpolated to allow estimates for the five-year period 2008-2012.

	1990 level (MtC)	Kyoto target (weighted)	Deficit (surplus) emissions A1	A2	A3	B	C1	C2
Russian Federation	650	0.0%	-102	-9	-367	-877	-532	-552
Ukraine	178	0.0%	-28	-3	-101	-241	-146	-152
TOTAL	828	0.0%	-130	-12	-468	-1117	-677	-703

Each scenario yields a significant carbon bubble. The smallest bubble (12 MtC, $1.8 billion) occurs in scenario A2 (high economic growth and carbon-intensive technologies).

The largest bubble is in the "middle course" (B) scenario, which IIASA-WEC reviews[2] suggest is the most likely outcome. In this scenario, continued weakness in the former Soviet economies dampens growth in emissions. Stronger economies and continued use of carbon-intensive fuels (e.g., coal) in the West raises demand for permits (if Western regions intend to comply with the Kyoto Protocol), which suggests that permit prices will equal or exceed our middle estimate.

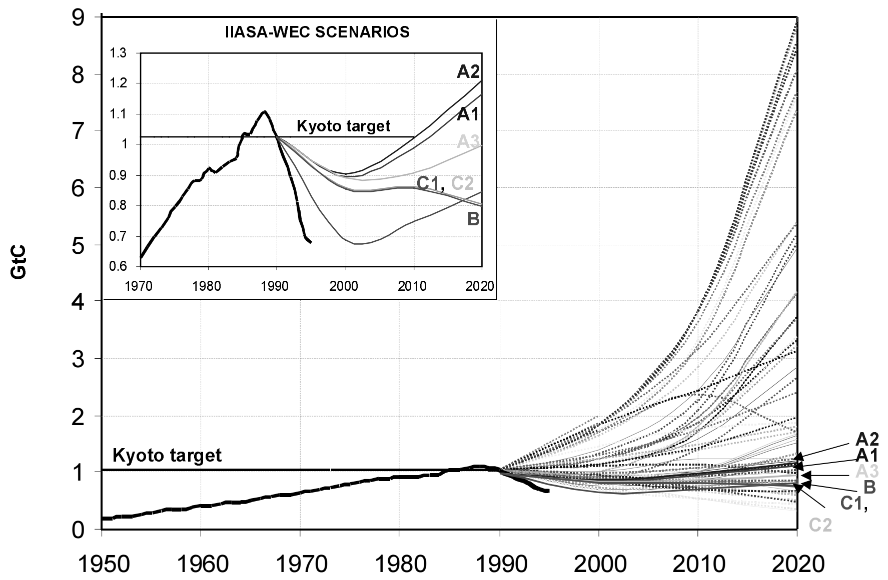

Figure 2: **Emissions of CO_2 from the former Soviet Union due to combustion of fossil fuels under the six IIASA/WEC scenarios[2] (heavy colored lines and inset), other scenarios[3] (light lines), and actual emissions (black line). We show the whole former Soviet region because Russia and Ukraine constitute the largest portion (80%), historical data for the separate republics are unavailable prior to 1992, and most models and scenario exercises (including IIASA-WEC) aggregate the region as one. (Data sources same as in figure 1.)**

Although we have excluded the non-CO2 greenhouse gases, if data and models were available to include them in the analysis the results would be similar. Russia's official "communication" to the FCCC indicates that fossil fuel CO_2 accounted for 79% of greenhouse gas emissions in 1990, with the balance due to CH_4 (18%) and N_2O (3%).[20] (To allow comparison with official reports, emissions of different greenhouse gases are converted into common units using the standard 100-year "global warming potentials" adopted by IPCC in 1995.[21,22]) Other recent (1997) Russian studies confirm these proportions.[23,24] Russia has not submitted emission estimates for the other three greenhouse gases included in the Kyoto Protocol (hydrofluorocarbons, perfluorocarbons or sulfur hexafluoride); however, in other industrial countries emissions of these gases constitute only a small fraction (<3%) of total emissions.[20,25] When the Kyoto Protocol was adopted Ukraine had not submitted any official emissions inventory, but the proportion of fossil fuel CO_2 and other greenhouse gases are likely to be similar to the Russian situation.

We also exclude from our analysis CO_2 due to land use change and forestry. Proper management of Russian forests could potentially yield a large carbon sink and an even larger carbon bubble. However, accounting rules for sinks in the Kyoto Protocol are still hotly contested, and the net carbon content of Russian lands (especially forests) is highly uncertain and variable with time. Some studies suggest that Russian forests were a large net carbon sink (184 MtC yr^{-1}) in the early 1990s.[26] A recent survey by the government of Russia concluded that the net sink was 110 MtC sink in 1990 and rose 50% in the early 1990s due to decreased logging of Russian forests.[24] Russia's official

FCCC communication reports a net sink of 107 MtC in 1990.[20] However, the only comprehensive independent analysis concludes that Russian forests were a net source of 69 MtC per year for 1988 to 1993 (see methodology in ref. [27], updated with a critical review of other studies in ref. [28].) The range of these numbers (approximately 200 MtC per year, 1000 MtC over five years) suggests that uncertainty in the forest carbon flux is comparable with the largest estimate for the Russian and Ukrainian carbon bubble for the five year Kyoto budget period[*]. Since the Kyoto Protocol explicitly includes forestry (ref. 1, Articles 3.3, 3.4, and 3.7), it may be wiser to delay creation of a legally binding emission trading system, with substantial resource flows, until there is some certainty that the resource flows can be estimated and monitored.

Table 4: Estimated value of the Russian and Ukrainian carbon bubbles. We use three plausible permit prices, but some combinations of permit prices and scenarios are not realistic ("nr"). In the A2 scenario, low permit prices are implausible because high emissions would raise demand and permit prices, perhaps above $150 per ton. In the C scenarios the bubble is not needed for compliance with the Kyoto Protocol and thus permit prices are likely to be low or zero.

	Tax level (US'90 $ per tC)	A1	A2	A3	B	C1	C2
Russian Federation	20	2	0.2	7	20	10	10
Ukraine		1	0.1	2	5	3	3
TOTAL		3	0.2	9	25	13	13
Russian Federation	50	5	0.5	20	40	30	30
Ukraine		1	0.1	5	10	7	8
TOTAL		7	1	25	50	37	38
Russian Federation	150	10	1	60	130	80	83
Ukraine		4	0.4	20	40	20	20
TOTAL		14	2	80	170	100	103

Other studies have shown that the Kyoto Protocol's targets will have little impact on the long-term concentration of carbon dioxide in the atmosphere.[29] However, if the large bubble transfers were tied to low-carbon infrastructure investments (e.g., gas

[*] This paper is about the carbon bubble due to the fossil energy system. The purpose of this calculation on the forest carbon flux is merely to illustrate the range of uncertainty, importance, and relative magnitude of terrestrial carbon in the region of the former Soviet Union. Intense political negotiations are under way on how to account for carbon fluxes as part of an emission trading system under the Kyoto Protocol. Large carbon fluxes, and the attendant implications for an emission trading system, probably also exist in other regions. For a recent paper in the huge literature on this topic see, for example, Fan, S. Gloor, M., Mahlman, J., Pacala, S., Sarmiento, J., Takahashi, T., and Tans, P., "A Large Terrestrial Carbon Sink in North America Implied by Atmospheric and Oceanic Carbon Dioxide Data and Models," *Science*, **282**, 442-446 (1998), which argues the current carbon sink in North America is approximately 1700 MMtC.

pipelines, safe nuclear power) the resulting pattern of energy development could reinforce decarbonization of the world energy system. Indeed, the bubble revenues are comparable in magnitude with the entire investment being made in the energy system of the former Soviet Union. For the 6 IIASA-WEC scenarios, the MESSAGE model computes that investments in the energy system of the entire former Soviet Union during 2008-2012 range from $117 billion (scenario B) to $206 billion (scenario A3). Investments in zero-carbon and low-carbon natural gas range from $80 billion (scenario B) to $120 billion (scenario A3). Earmarking could yield additional pipelines to ship vas Russian resources of low-carbon natural gas Asia—which cost approximately $10 billion per 1000km—and thus offset the growth in carbon-intensive coal, which would slow global warming and also combat Asian acid rain. The main proponents of emissions trading, including Russia and the United States, have indicated opposition to earmarking of carbon trading revenues.[30] However, so far there has been no discussion of whether and how to link such investments at a high political level (e.g., see ref. [31]). By reinforcing the long-term objective of the FCCC and avoiding a simple transfer of billions of dollars, such earmarking could also raise the political feasibility of emissions trading of the bubbles under the Kyoto Protocol.

This analysis also provides an estimate of the date when Russia and Ukraine will be unable to comply with the Kyoto Protocol without actions to regulate their carbon dioxide emissions. Absent external pressure (e.g., trade sanctions), Russia and Ukraine will exit when the bubble bursts and revenues stop flowing. Studies on Soviet participation in international environmental agreements demonstrate that the country complied with international agreements when it was strictly in its interest to do so, which is a pattern that continues with Russia.[32] That line of argument suggests that Russia and Ukraine would exit the Kyoto Protocol as early as 2011 (A2 scenario), or never (C scenarios). If a 1990 ceiling on emissions continues beyond the Kyoto budget period, in the most likely scenario (B) the bubble would burst only in 2040. Exit might be averted by internal pressure to comply with environmental agreements that is evident in advanced democracies where public interest environmental groups are politically strong, but such groups are generally weak and inactive on the global warming issue in the former Soviet Union.

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